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BUILDING ENGINEERING

FINAL DEGREE THESIS

PLATFORM FOR FACADES DURABILITY ANALYSIS AND ITS IMPLEMENTATION IN OLSZTYN, POLAND

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In these lines I would like to have a memory for all people who have made possible this experience that has led this project. Their support has been essential and without it, nothing would have been possible. So I consider of righteousness, that they are some part of this project by being mentioned in this space.

In the first place, I would like to mention to Dr. Carles Serrat i Piè. His passion for statistics and for teaching has awaked in me a motivation thta I never have expected. Thank you for trusting me to carry out this fascinating project.

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At the personal level I want to remember Mar, my girlfriend. She encouraged me from the very beginning to begin this adventure, despite the fact that this has kept us away for a while. She makes me try to be a better person every day, and I look forward to the future for all the moments that I'm sure, we will share together.

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I'll forget some of them for sure. They form an important part of my life. They've supported me in good and in bad times, and the experiences we have lived together have enabled me to success in this one.

SUMMARY

This project aims to implement a methodology to determine the durability of the facades of civil buildings in the town of Olsztyn, Poland. This methodology was previously developed at the Building Laboratory of the Building Engineering School of Barcelon, one of the schools of the Polytechnic University of Catalunya (UPC).

The implementation of the methodology has been developed in the context of a cooperation agreement between the UPC and the Faculty of Geodesy and Land Management at the University of Warmia and Mazury, of the aforementioned Polish city. Of it is expected to lay the foundations to create a core research in Poland, which encourage future researchers to further develop the methodology in a different environment than the explored so far, thus achieving new findings and improving the existing procedure against new difficulties.

As for this methodology is referred it deals with the study on durability of statistical techniques in structural elements, such as building facades. The study starts by exploring the state of degradation of these elements in different cities by designing a systematic collection of data. The main goal is to establish degrees of involvement and, at the same time, assess if we conclude with would define benchmarks for proving the durability behavior of injuries in facades across.

In the literature on survival in the building environment, it appears that this is a very young field in the scientific environment, and in which research is still short. However, we believe that it has a notable interest to find reliable criteria to provide knowledge in order to establish preventive measures for the conservation and maintenance, which are in favor of sustainability, economy and social coherence in the sector of building.

To achieve the proposal we have deepened into the understanding of survival statistical science and how they can identify enough robust estimators that are able to respond to the items to be pursued in this work through the observed data in a representative sample.

The conclusions that this paper reaches provide an important qualitative progress towards the stated objectives and, in turn, raises what should the strategies and analysis techniques be in future research. This is the reason why we are satisfied with the achievements, because it shows us the way to achieve major goals in the knowledge of survival techniques applied to building.

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INTRODUCTION

1 INTRODUCTION

1.1 Project's theoretical frame

The aging of the existing buildings in the urban areas of our country will present a new reality in the real estate sector in the near future. This situation should lead us to greater ethical responsibility in the different models of intervention used so far. These differences and the growing need to establish criteria for sustainability and efficiency in the conservation of built heritage everyday, mark the foundations on which it will base this paper studies.

The debate on conservation in consonance with sustainability must necessarily determine the durability of the building, as this is definitely the parameter that determines and sets the balance between the assumptions above.

Therefore, the goal of this work is to propose a system for determining estimators based on durability techniques, to establish in a more rational way, the application of a built elements' trusted method of behaviour over the time.

It is important to be aware of the true state of the buildings at the present time in which there is a crisis in the sector to correct historical mistakes that have led to the loss of the culture of heritage conservation. Such a situation demands the need for a large-scale rehabilitation of buildings with very high costs for lack of foresight and involvement in a sufficiently known problem.

The body of this work is focused on a diagnostic study, and seeks to establish which analysis trends must exist in order to predict the evolution of degradation of the elements that form a building and determine which actions would be necessary to anticipate the facts. Neither therapy nor the causes that have led are subject to study, however, there are considered the situations that lead to a common aging of these elements.

In the same context, we have found a wide variety of publications and authors who have been interested in the issue of the theory of durability and possible failure, as well as confidence in the reliability of forecasts of service, both elements and mechanisms or subsystems. But most of the consulted literature is focused on industrial machinery based systems or in the environment of service facilities, which generates a direct benefit from the use phase against equipment failure or shutdown. It is therefore necessary to emphasize that these advances in knowledge of the behaviour over time of industrial equipment have cleared us some doubts about which way we should take to translate these experiences in survival construction field and more particularly in existing buildings.

The conservation philosophy and rigor that must be taken to achieve maximum knowledge necessarily involves knowing what strategy has to be proposed to implement specific maintenance plans in each particular case. The Spanish Association for Standardisation and Certification AENOR defines maintenance as *"the set of activities intended to maintaining or restoring an asset to as specific state or to a given safety operational conditions in order to comply with a required function."*

We want to emphasize that there are differences between the conservation of a product and the maintenance of it. The first establishes which are its characteristics based on the elements that form it and its durability based on the intrinsic ability of the materials used, versus maintenance that determines which actions are necessary for these design conditions are maintained over time and what will be its functional or risk of failure throughout its life depreciation.

This is an important feature of the study as it will make a policy decision as to the strategy to plan a proper maintenance plan in the entire built park in cities.

The current situation through which passes the real estate sector, the regression of new buildings and the forced necessity of setting goals into the built park, makes this paper may seem opportunistic. However, we think that if we look with a vision of logistical criteria it can be understood the need to reach at last to confront the problem from a panoramic view of sustainability, durability and unavoidable social responsibility towards maximum efficiency of the built parks.

1.2 Purposes of the project

The differences and sometimes the weaknesses of the models used by the technicians in the intervention of the existing buildings that constitute the built heritage, and the inescapable need to establish and implement sustainability criteria and efficiency in how it has to act for conservation and later maintenance of existing buildings, are the trigger to take into consideration the need to undertake this work.

Through our personal experiences many methodological deficiencies have been highlighted in this area, so that an investigation capable of generating discussion, scientific material and reliable analytical models to guide responsible for management and edified heritage care is necessary. In this context, the purpose it aims to achieve this paper is to explore which are the existing techniques on the durability analyzing the application of the most appropriate models in the existing building, proposing a model of a specific building system, in this case, facades of the buildings and determining the advantages and / or opportunities that may be offered by the action model on the technical, social and economic environment.

The objective pursued by establishing a specific model, is to identify differential factors applicable in the chosen constructive subsystem, demonstrating the benefit that involves to the construction sector and the social sector, and with this objective will come the following lines of development:

- Implement the methodology of analysis in the city of Olsztyn, thus providing the project a global character which is one of the main pursued objectives in order to expand the model.

- Define which ones are the antecedents considered and which concepts are particularly of mention for the understanding of the different proposals.

- Determine how the methodology for data collection is established and which parameters are to be taken as fundamental.

- Motion for reliability techniques in the building, based on proposals with a nonparametric approach to durability.

- Application of the model on existing facades based on previous theoretical studies on a real sample in the city of l'Hospitalet de Llobregat as a practical illustration of the proposed model.

- Analysis of the kind of estimators that is established between the model used and the results obtained.

- Determination of improvements in future projects in data collection and new lines of research.

The starting hypothesis that is intended to prove is that the application of a based on the statistical analysis of reliability and creating indicators system, show its efficiency and achieve improve results to anticipate the failure or collapse of the studied element, either as part Single facade or the whole set of it.

The paper also aims to establish a methodology and a policy of effective intervention and sustainable in the durability of the buildings.

Finally, the results obtained will be submitted for publication in professional journals in the field with an impact factor and indexed in JCR.

1.3 Methodology used on the project

The methodology used in the work is held in a study based on a systematic identification of inspection performed with sheets on existing facades. We opted for choosing this method to understand which is the best way to collect information capable of responding to the questions pursued.

The domain analyzed will focus exclusively on the facades of the city of l'Hospitalet de Llobregat, based on a study conducted at the Laboratory of Building between 1998 and 2002 by students undergoing Final Project. This study has allowed the existence of a database necessary and sufficient to begin to determine estimates of durability over time.

Under the umbrella of Laboratory Building, in which one of the lines of work and research is the behaviour and cataloguing of large urban areas, some studies have been developed in several Spanish cities like Barcelona with a total of 5,367 inspected the park facades, l 'Hospitalet de Llobregat with a total of 13,193 inspections and the city of Palma de Mallorca Esporles in 291 facades. On countries of the American continent 525 facades have been inspected in the city of the Federal District of Mexico, in Santiago de Chile 1403 and in the same country Valparaiso 396. Make a special mention of this last work because it served for the area declared by UNESCO heritage of special interest for Humanity.

In each of the specified cities, we have collected the different types of injuries and constructive elements of the facades affected and defined the level of the injury. The choice of the city of l'Hospitalet de Llobregat against the remaining, respond to the greatest amount of inspected facades, the uniqueness of that this was a built park that had not been subjected to any intervention before the date inspection, and finally, it had all the cadastral information with the dates of construction of buildings.

The selected sample contains all the requirements to be studied, as there wasn't, at the time of inspection, any intervention after the date of construction. This is sufficiently representative for its magnitude and also unique in that all the facades have been exposed equally to aging and use during different periods of time.

In order to establish methods of analysis and reach the interpretation of field data, has had the invaluable collaboration of the Department of Applied Mathematics I, and especially, the Institute of Statistics and Mathematics Applied to Building, and his responsible and director of this work Carles Serrat i Piè.

The reliability analysis methodologies, how to treat information, what results are sufficiently representative, and how you can get to mark estimators based on durability adapted to the building, are issues that have been dealt from the statistical point of view and have to how to respond to intervene efficiently in built parks.

1.4 Contributions of the project

The present work aims to validate an application of an analytical system that allows with sufficient reliability, know the time-dependent behavior of different elements that are present on the facades of buildings.

Its main contribution is to develop a sufficiently robust tool to determine the evolution experienced by elements of the facades exposed to the weather and use to anticipate depreciation or failure. This has to provide benefits and technical knowledge to the performers of rehabilitation projects as well as to society that handles them.

Their secondary contributions are:

- Start a long-term project, which in turn enables to internationalize the methodology for estimating the durability of the elements of the facades.
- Identify possible singularities in existing buildings of the city of Olsztyn which will be inspected.
- Characterization of the inspected building stock and definition of the main constructional features of buildings.
- To study the environment of mathematical disciplines and the latest developments on survival.
- Ask how it performed nowadays the intervention in facades and if there are chances for improvement.
- Add the study of one case of large urban area to the literature of successful experiences for diagnosis and facades conservation.
- Point out potential risks and problems in the implementation of the proposed model.
- Serve as a start point in the sector as a principle of good practice and example for future applications.

PART I: GENERAL METHODOLOGY AND STATISTICAL PROCEDURE

2 STATE OF THE ISSUE

2.1 Introduction

The building sector has recently shown the necessity to use information systems increasingly more complete to help plan, monitor and manage efficiently the park built with the help of better information, more reliable and continuous. This is largely due to those responsible for controlling and heritage management are becoming more sensitive to the need to deal with a constantly mutating environment, with strong social and political demands.

As we shall see in more detail in the following chapters, par excellence systems are the predictives, in principle, deeply rooted in other areas of knowledge and that little by little are being introduced in the existing building area.

For all that is necessary to create proposals that are as objective and quantifiable as possible, so that its application can be taken as extrapolated to the whole framework of the problem facing us.

As a point of observation it has been investigated in the field of the existence of works or authors who have been concerned about similar issues that we are proposing, focused on durability, risk and survival.

2.2 Detection of the state of facades overall degradation

The first reference we have record on inspections of large urban areas was performed by Jordana and Gibert (1999) in the study "pilot Pla de l'estat de les façanes in edificis de l'Eixample". In this study, the President of ProEixample, Xavier Casas i Masjoan, expressed the need for studies of this part of the city of Barcelona due to the aging of the buildings, together with its population. This situation demands that the Eixample has the need for rehabilitation policies, which, until 1996, were maintained on a unwise state. Barcelona City Council through ProEixample remarks the introduction of the publication, the rigor of the project and thanked study leaders work done.

This work comes under two lines of research within the Laboratory Building of the Universitat Politècnica de Catalunya.

- Line of “Total quality building process” directed by Francesc Jordana.
- Line of “Modeling, durability and maintenance building” directed by Vicente Gibert.

The project objective was to detect and remove imminent risks of detachment, identify other kinds of injuries to their magnitude and severity, and whether it could consider the phenomenon of the age of the building as a key parameter of the dysfunctions found in the facades.

To conduct the study, a total of 250 Barcelona facades were analyzed, distributed according to the constructive periods represented in the Eixample district based on *Table 2.1.*

The collection of data was performed using sheets that provided information on types of actions classified as:

- Immediate: where a elimination of the risk is required.
- Short term: where it has to be intervened before a year.
- Medium term: where intervention has to be planned between one and five years
- Long term plazo: action between five and ten years.

- Maintenance: where they have to establish the necessary conditions to prevent premature degradation.

Tipology	Pre-modernism	Modernism	Post-modernism	Post war	Expansion	Contemporary
Year of construction	1860 - 1900	1888 - 1915	1910 -1936	1940 - 1960	1960 - 1975	1975 - 1997
Existing buildings	2.313	701	2.584	1.206	1.452	829
% buildings	26	7	29	13	16	9
Inspections	129	43	27	22	17	12
% of sample	51	17	11	9	7	5

Table 2.1: Distribution of the studied sample (Adapted from: Jordana y Gibert, 1999)

The result of damaged facades accounted for 13.2% of lesions with immediate risk, 8.3% in the short term, medium term 29.4%, 35.9% long term and 13.2% for maintenance.

Based on a descriptive methodology, within the project were reached the following conclusions:

- *The degree of conservation and injury does not depend exclusively on the age of the building.*
- *The items shown further degradation are projecting from the plane of the facade.*
- *The buildings of pre-modernism, post-modernism and modernism show more injuries in the continuous finishing elements than in the discontinuous ones.*
- *The analyzed sample is considered insufficient to undertake further studies aimed at determining the durability.*
- *This experience serves as a model to continue experimenting.*

The work done by Jordana and Gibert introduces a methodology for inspection in large urban areas, which is quick and effective for exploration and data collection. It is capable of displaying a reality of the state where the facades are based on the situation, the type of injury, its magnitude and, finally, its severity. This study provides quantitative evidence of the state of the facades inspected at the time of inspection, but does not apply to these results survival theory to do a prediagnosis of the evolution of degradation in advance.

2.3 Introduction of survival functions for determining the buildings' service life.

Buergel-Goodwin et al. (2005) pointed to the importance of having information about the survival functions of buildings and building elements.

The authors believe that the mere adoption of the values given by the literature, without evaluating the various factors of influence, leads to arbitrary results. It would be necessary therefore to use a more analytical method to estimate the life of an element such as factor method described in ISO-15686-1: 2000 standard. This method, discussed above, is based on lifetime reference and in a number of modified factors that relate to the specific conditions of the case considered. The lifetime is based on seven parameters (A to G) depending on the inherent quality, environmental and operating conditions. However, they conclude that the analysis of a large number of existing buildings and their components from the combination of survival functions with levels of degradation provides more reliable results, at least for buildings under similar conditions.

They performed an empirical investigation in which was possible to determine the actions of maintenance, repair and replacement of several buildings for a long period of time from records of the owners of public buildings. In general, the maintenance strategy public buildings intended the preservation of value in the long term. The decision to renew is based on a depth review of the building. Due to the financial situation of the State Administration of Germany, only were held urgent actions, since there were no funds for preventive measures.

The repair and replacement of building components such as windows, interior doors and flooring, were examined for survival analysis buildings in three cities in Germany (Gengenbach, Offenburg and Freiburg). Despite the small number of buildings examined, they showed an especially long life, possibly due to regular maintenance and the need to maintain the building elements as long as possible.

To determine the life cycle of the buildings it was necessary to make a first analysis of the renewal cycle in which renewal deadlines set were examined, the reason for his intervention and the elements that have been affected.

Differences in lifetime clearly show that the age of the building elements is only one of many factors that lead to the repair or replacement. The authors determined the survival functions of the elements starting from a previous study in which operations reconstruction, repair or replacement were established. Then they applied a similar method on public buildings which showed similar results. After the analysis, it was found that public buildings are less subject to fashion and short-term goals, and that its history is determined by an aging of regular maintenance, replacement and changes due to building regulations. In other words, the combination of quality of traditional construction, maintenance, repair and remodeling efficient, leads to long duration of both structural elements and buildings.

These authors introduce the survival functions for determining the life of a building or construction elements, however the sample used is insufficient for the characterization of the survival time, therefore all that are used are alleged and unverified.

The specific literature found about survival or reliability behavior of the existing building is scarce and, in turn, shows different methodologies and analysis techniques tend to look the same goals.

In the present project we develop survival functions in order to bridge the gap in the consulted literature. Our proposal will consist of a nonparametric statistical analysis of data obtained through inspections on an adequate sample of facades of residential buildings, in order to identify indicators that provide information on the behavior of the lifetime of the different construction elements.

3 DATA COLLECTION DESIGN

3.1 Model definition

From a repeatedly events of elements drop in the public road in different cities in Spain and specifically in Barcelona with fatalities, it was awaken the need to investigate the causes and the true state of the elements forming the facades and what is the potential risk that similar events reproduce uncontrollably. This political and social concerns in his time was widely publicized by the media, and led to propose more general studies of the state of the parks built in different cities.

Faced with this public concern, the technical response was immediate but not sufficiently effective since no similar experiences were held or had sufficient databank to propose a shock-strategy conclusively. These prompted the Laboratory Building cared for the analysis of the causes of the events since its inception and deepen in the global behavior of large urban areas over time.

The cities of Barcelona and L'Hospitalet de Llobregat, along with others, were among the first to commission a study of this nature. This fact allowed us to reflection from its origins, meaning that the project will not only had to solve the problem but also had to serve to accumulate experiences for further reflection and application of advanced techniques in the behavior of the built, neglecting faster and unpredictable systems to over time.

That is why the approaches that was prefixed in the beginning to develop the project, took into account some parameters that were essential requirement such as public safety, and social motivation and commitment of the properties users towards conservation.

To achieve the basic objectives it was needed to establish the strategy that was able to consider requirements such as:

- The size of the sample, which consisted of all its elements, bringing the study of a population sample character.
- The allotted time, which might not be excessive to avoid losing objectivity or alteration by repair interventions that modify the results.
- Inspectors, with a previous preparation of which were the objectives sought, what kind of project was developing and how they had to perform the survey.
- Individuals (facades), how to sort them by study groups to apply logical behavior over time comparisons.
- Things to detect within the observed elements and how to sort them by categories.
- Which dysfunction showed how to classify determining both its magnitude and severity.
- With what system was all this casuistry of information could be done to then be processed for more conclusive studies.

These sections should be performed with sufficient reliability to achieve the objectives in order to respond to political and civic concerns of the era.

The amount of facades to inspect was huge and a fact so far unknown. With the usual, and very rooted in the professional community, prospecting systems the project was unreachable from both technically and economically point of view. Therefore, it had to propose a new model that did not penalized the rigor of inspection and met the requirements posed of origin.

This point, which was crucial, was resolved by avoiding the need for access to buildings to inspect them. This fact which seems lower order, allowed us to significantly reduce the time of data collection so as to develop the project in time and form.

For human resource it was decided to integrate students of Technical Architecture in realization phase of the final year project of their studies. They entered a preparation and learning of fieldwork under a practical theoretical model accompanied by tutors project researchers. This homogenized all the groups so that the results were somewhat scattered and inspection routines fully protocolised.

Work teams were formed into groups of two inspectors, who possessed binoculars and a camera to display all elements injured in the upper parts of the facade in order to realize the degree of hazard of the injury.

Finally, it was necessary to establish a data collection system, it had to be fast, not create doubts in the collection of incidents, be standard and capable of bringing maximum information in minimum space. To achieve the expected results, documents able to customize each inspected city facades were designed.

In order to segment without losing the clustering of facades in study, was searched how to differentiate generically virtual planes that could be formalized to determine which elements are part of them and identify them in each of the established levels. The basic diagram of this classification is shown in *Figures 3.1a* and *3.1b* where there is firstly identified with the number 1 the plane of enclosure and which may be presented as exempt from the main plane, with the number 2 elements that they are cantilevered and number 3, those forming the bodies of the tribunes.

A more consistent with the formal design of a generic facade representation shown below, in which the three basic levels with possible elements of such are noticeable: a closeup of the road alignment, background formed by cantilevered elements, and a third plane regarding possible tribunes.

Once established the planes of interest, proceeded to determine what information was needed to collect to respond to the type of intervention, whether it be to eliminate the risk as for enter a process of adaptation or improvement of the facade.

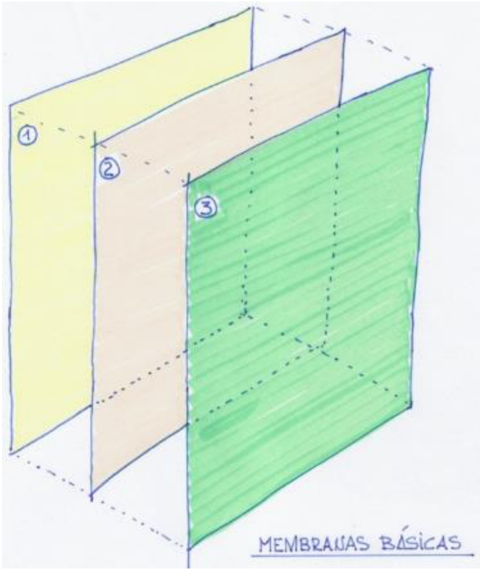


Figure 3.1a: Diagram of three basic membranes Source: Gibert-Royano 2010

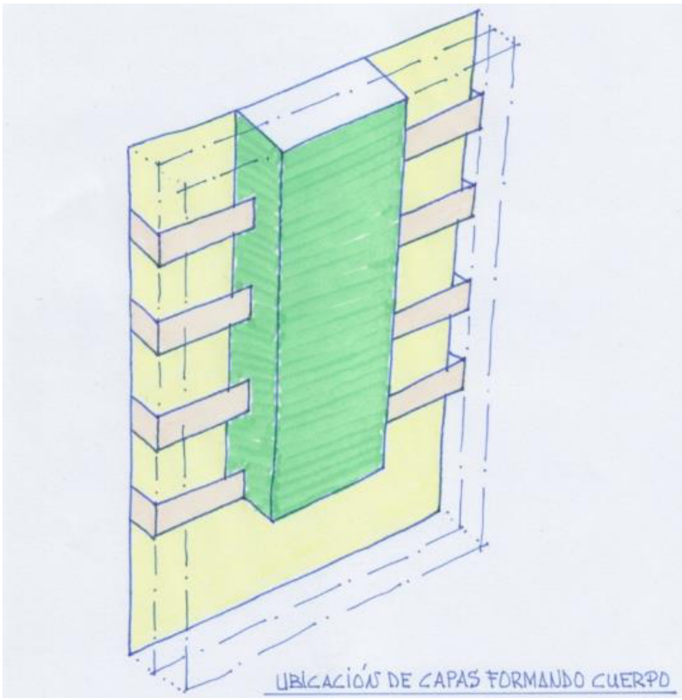


Figure 3.1b: Location of the layers that form the body Source: Gibert-Royano 2010

The passage between the overall strategy and operational was widely debated and controversial, in the end we opted for a system of collecting information of sheets that incorporate advantages over more classical models of raw data collection. For this, two large blocks of data, one focused on the collection of urban, of building and usage information that could identify the property and a more specific towards the state of degradation of existing facades on inspected elements were determined.

In the fulfilment of everything that was object of study to achieve the goals and allow, without loss of time, take the maximum information for further studies led to the diagrams in *Figures 3.2a* and *3.2b.*

Distinct groupings of information that definitively form the comprehensive body of the inspected item, together with its immediate urban and legislative environment are set in *Figure 3.2.*

GENERAL SHEET

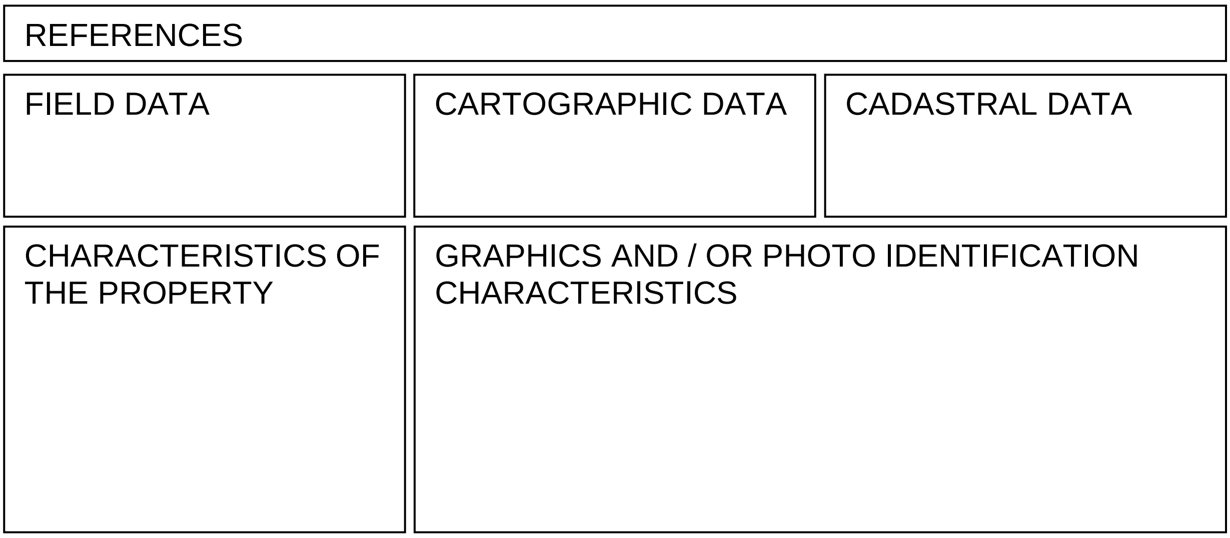


Figure 3.2a: General sheet. Adapted from: Gibert-Royano 2010

This first sheet collects data from various administrative bases which compared to the field would provide the homogenization of municipal information, and will characterize the property by its age, type, use, and its historical dependencies.

Starting from this information, it was thought only in the inspection of the facades sheet, and we understand that is what has undergone a major transformation regarding the concept of traditional sheets. It has sacrificed the possibility of personal notes by the inspector, totally subjective, by more standardized, predefined observations that even seeming to the potential of inspector is lost, unified decision making.

The diagram in *Figure 3.2b* shows two main sections in which, systematically, are established left the various parts into which have subdivided the facade for study, and the right the kinds of injuries are defined and for each of them, the degree of damage and the potential risk of them.

FACADE SHEET

REFERENCES	
SUBDIVISION OF THE FACADES ELEMENTS IN: ▪ TYPE OF ELEMENT ▪ TYPE OF MATERIAL ▪ OTHERS	▪ DETERMINATION OF AFFECTATION, LOCATION, MAGNITUDE AND SEVERITY THAT SHOWS THE FACADE BY: ▪ MEMBRANE ▪ ELEMENT ▪ SUBELEMENT ▪ MATERIAL

Figure 3.2b: Facade sheet Adapted from: Gibert-Royano 2010

Notice that the first, *Figure 3.2a* shows purely identifying issues that could not be present in the study to be carried out, but they are useful when you want to be associated with effects caused by some of the injuries presented by facade. However, in the second sheet the target is very different, as we seek to include which parts of the facade are to be considered in the inspection and how they can be generalized leaving margin of variability in the material used to subsequently diagnose it with maximum objectivity.

3.2 Determination of the elements to be observed

In order to determine the elements to be observed in the phase of inspection the criteria to follow in making decisions for the survey of data collection were established.

A general planning for different phases, shows where the information sources is established and how they are derived based on the various proposals for intervention to City Hall and that in turn, impact to property in order to the mechanisms of programmed intervention are given.

There exists an agreement with the Council of Hospitalet de Llobregat to establish a direct channel of information so that the information collected in the field inspections that might be relevant and could require rapid intervention, reach the municipal authorities, so they can perform quickly the appropriate actions to eliminate a possible risk to people.

Set sections, subsections and items to be observed in the inspections, as well as the different concepts of classification of the status of each facade and, following the path of the information in the whole process, field sheets were designed for being used by the different groups of inspectors to data collection.

The functional significance of the sheets and the apparent rigidity of its contents are basic to determine robust enough information of the reality found in the field. It was necessary to instruct inspectors explaining how they had organized the sheets, its fields and what kind of information contained, as well as what criteria should had been taken against the detected injuries.

Here we show the different items that were set in the field document considering that are the most common both in the type of injury as for its magnitude and severity. In *Table 3.1* the classification of the type of injuries studied in the sheets is shown (Spanish translation in red), and finally, an acronym that identifies them.

Injuries object of study							
Spalling	*Cracks*	*Material degradation*	*Deformation*	*Humidity*	*Oxidation*	*Swolen*	*Flakes*
Rotura	Fisura	Degradación Material	Deformación	Humedad	Oxidación	Bufado	Desconchado
T/R	F	DM	D	H	O	B	ES/DC

Table 3.1: Considered Injuries classification Adapted from: Gibert-Royano 2010

Once established types of injuries it was necessary to come to determine the degree of affectation that was shown for each of them. As already mentioned above, this type of inspections did not allow exact numerical measurements because no was acceded directly to the affected area. Therefore, it is quantified percentages and always referred to the set of elements considered. In Table 3.2 these percentages and identification which later will be displayed in the information field is defined.

% Affectation	Magnitude
< 25 %	Punctual
≥ 25 % y < 50 %	Local
≥ 50 %	General

Table 3.2: Relación de afectación y magnitude Adapted from: Gibert-Royano 2010

Upon completion of the classification of injuries and their degree of affectation based on the magnitude represented on the facade, the degree of risk that had was marked. Is worth noting that the risk assessment prioritizes effect on people and secondly, direct affectation on the building.

To accomplish this, six degrees of risk ranging from the well preserved until the immediate action to eliminate the same imminently were proposed. Risk levels considered are set out in Table 3.3, viewing on the severity of lesions detected with its role in technical language and temporal forecast of the required intervention.

Degree of injuries hazard	Severity of the injuries	State of injuries	Danger for people	Intervention	Maximum time for intervention
6	Inmediate	Very bad	Yes	Immediate	Days
5	Urgent	Very bad	Not yet	Short-term	1 year
4	Muy sever	Bad	No	Medium term	3 years

3	Severe	Important injury	No	Medium term	5 years
2	Mild	Lack of maintentance	No	Corrective maintenance	5-10 years
1	Symptom or doubt	First symptoms of injury	No	Diagnosis	More than 10 years
0	--	Good state	No	Preventive maintenance	--

Table 3.3: Hazard factors and consequences Adapted from: Gibert-Royano 2010

3.3 Methodology of data collecting

All starting points presented in the preceding paragraphs, and the definition of the parameters to consider, had to be translated into a field document to allow inspectors meet their goals a well as the ones of the project, that we have to remember, were inspections aimed toward large urban centers.

At this time has to retake the fact and the significance it had the prior training of the methodology and tools to be used by groups of inspectors. This training consisted of information sessions at the laboratory about the functioning of filling the sheets created and practical field work with tutors during the first inspections that were subsequently reviewed and discussed jointly by all groups assigned in areas inspected.

The sheets used are shown in *Figures 3.4b 3.4b* entirely developed and those presented how they have structured the identity fields and which elements are remarkable for their successful deployment in the field or office.

Note that the designed sheets preserve the modeled structure in section 3.1 of this chapter where the definition of model to be followed is discussed. Although apparently both the sheet of *Figure 3.4a* general information, such as *Figure 3.4b* specific information, appear complicated by the number of fillable fields, the result of evaluating the inspection was very positive because they did not generate doubts by the many possibilities neither led into error because most of the situations were found contained therein. Finally, only the fields that existed on the facades were filled so that the time taken for inspection all requirements never exceeded 15 minutes.

Both sheets contain highly valuable information for further study of behavior of the elements contained in the facades. In the first one birth date or construction, their physical characteristics and their geographical location, all valid parameters intrinsic to establish indicators of the elements studied appears. While in the second, all the morphology of the facade, its elements, name, location and material are collected. In this last case it may seem anomalous the distribution of proposed subsystems specified parts, but one of the objectives of this section is to be the maximum of generalist and adapted to the different existing building typologies on the facades.

We are especially satisfied with the block that forms the diagnosis of the facade of Figure 3.4b. In it various types of injury, severity and magnitude are combined, all in the same row of characterization of the element and its material. This fact was vital to allow computerization based on the fields created

In the following pages, by way of illustration, are shown examples of field sheets and the way in which must be completed for a proper data collection.

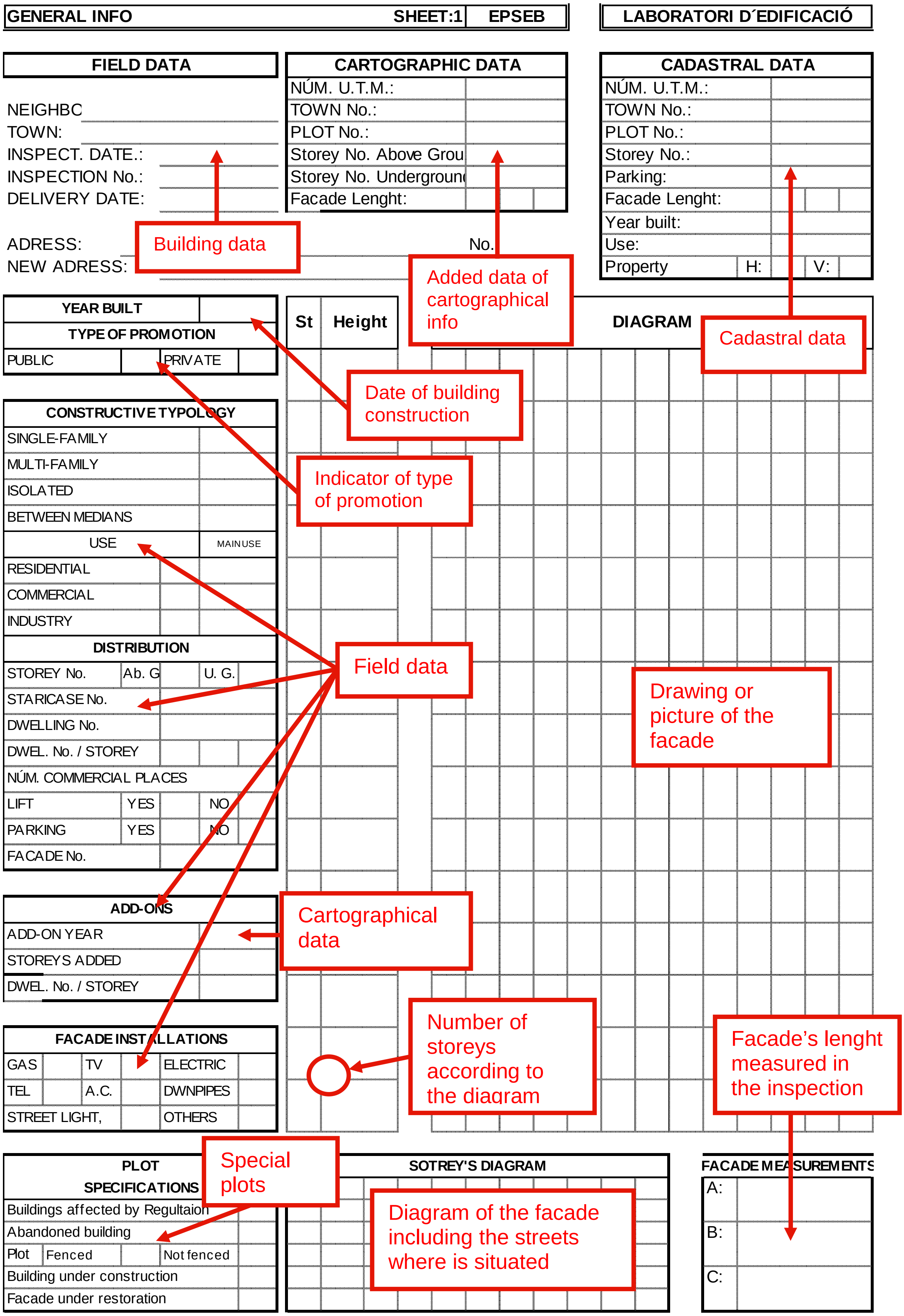
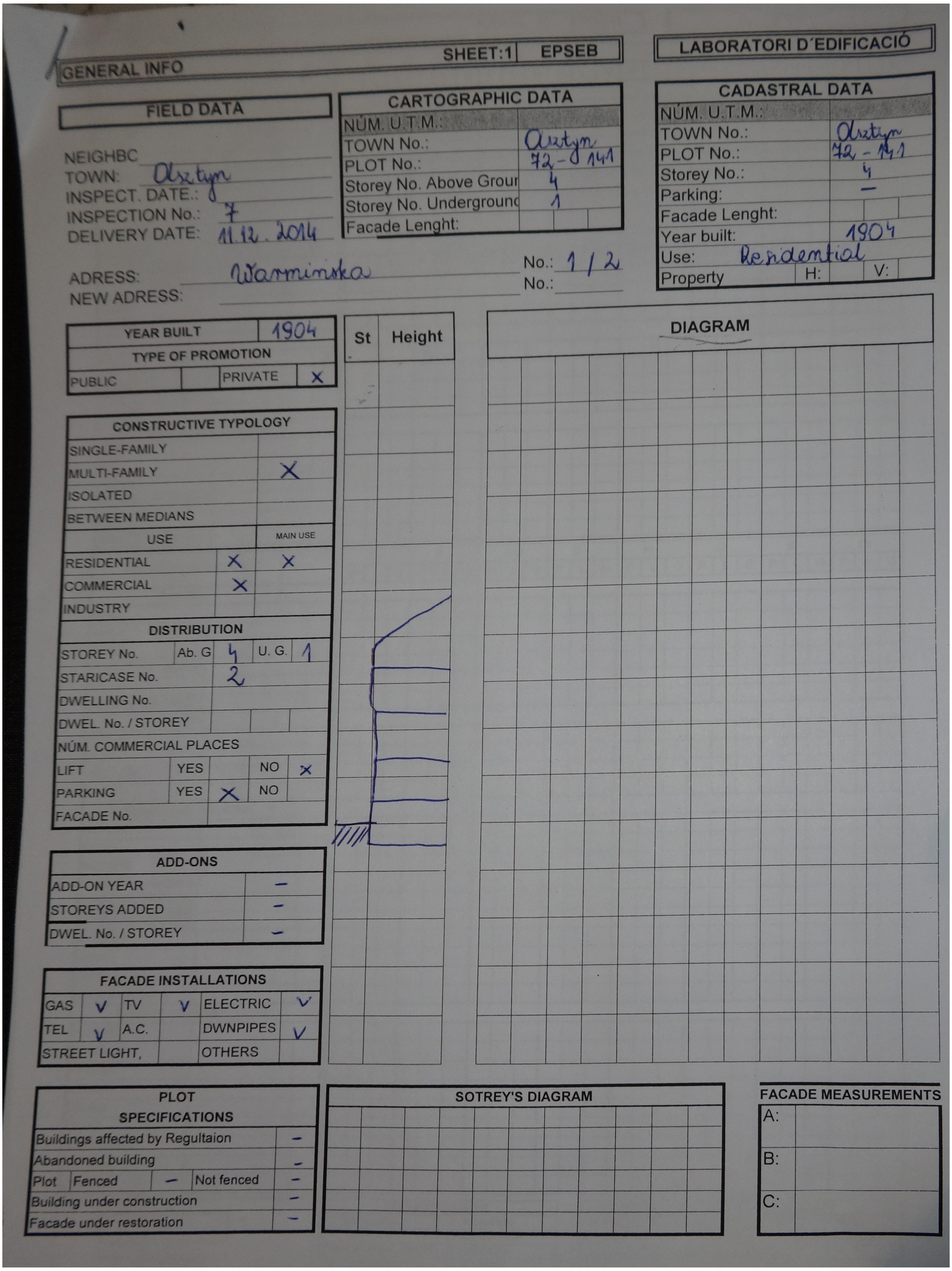


Figure 3.3a: General info sheet Adapted from: Gibert-Royano 2010



GENERAL INFO | SHEET:1 | EPSEB

LABORATORI D´EDIFICACIÓ

FIELD DATA

NEIGHBC
TOWN: Olsztyn
INSPECT. DATE.:
INSPECTION No.: 7
DELIVERY DATE: 11.12.2014

CARTOGRAPHIC DATA	
NÚM. U.T.M.:	
TOWN No.:	Olsztyn
PLOT No.:	72-0141
Storey No. Above Grour	4
Storey No. Undergrounc	1
Facade Lenght:	

CADASTRAL DATA	
NÚM. U.T.M.:	
TOWN No.:	Olsztyn
PLOT No.:	72 - 141
Storey No.:	4
Parking:	–
Facade Lenght:	
Year built:	1904
Use:	Residential
Property	H: V:

ADRESS: Warmińska No.: 1 / 2
NEW ADRESS: No.:

YEAR BUILT	1904		
TYPE OF PROMOTION			
PUBLIC		PRIVATE	X

CONSTRUCTIVE TYPOLOGY		
SINGLE-FAMILY		
MULTI-FAMILY	X	
ISOLATED		
BETWEEN MEDIANS		
USE		MAIN USE
RESIDENTIAL	X	X
COMMERCIAL	X	
INDUSTRY		

DISTRIBUTION				
STOREY No.	Ab. G	4	U. G.	1
STARICASE No.	2			
DWELLING No.				
DWEL. No. / STOREY				
NÚM. COMMERCIAL PLACES				
LIFT	YES		NO	X
PARKING	YES	X	NO	
FACADE No.				

St	Height

DIAGRAM

ADD-ONS	
ADD-ON YEAR	–
STOREYS ADDED	–
DWEL. No. / STOREY	–

FACADE INSTALLATIONS					
GAS	V	TV	V	ELECTRIC	V
TEL	V	A.C.		DWNPIPES	V
STREET LIGHT,				OTHERS	

PLOT SPECIFICATIONS			
Buildings affected by Regultaion			–
Abandoned building			–
Plot Fenced	–	Not fenced	–
Building under construction			–
Facade under restoration			–

SOTREY'S DIAGRAM

FACADE MEASUREMENTS	
A:	
B:	
C:	

Figure 3.3b: General info sheet, example

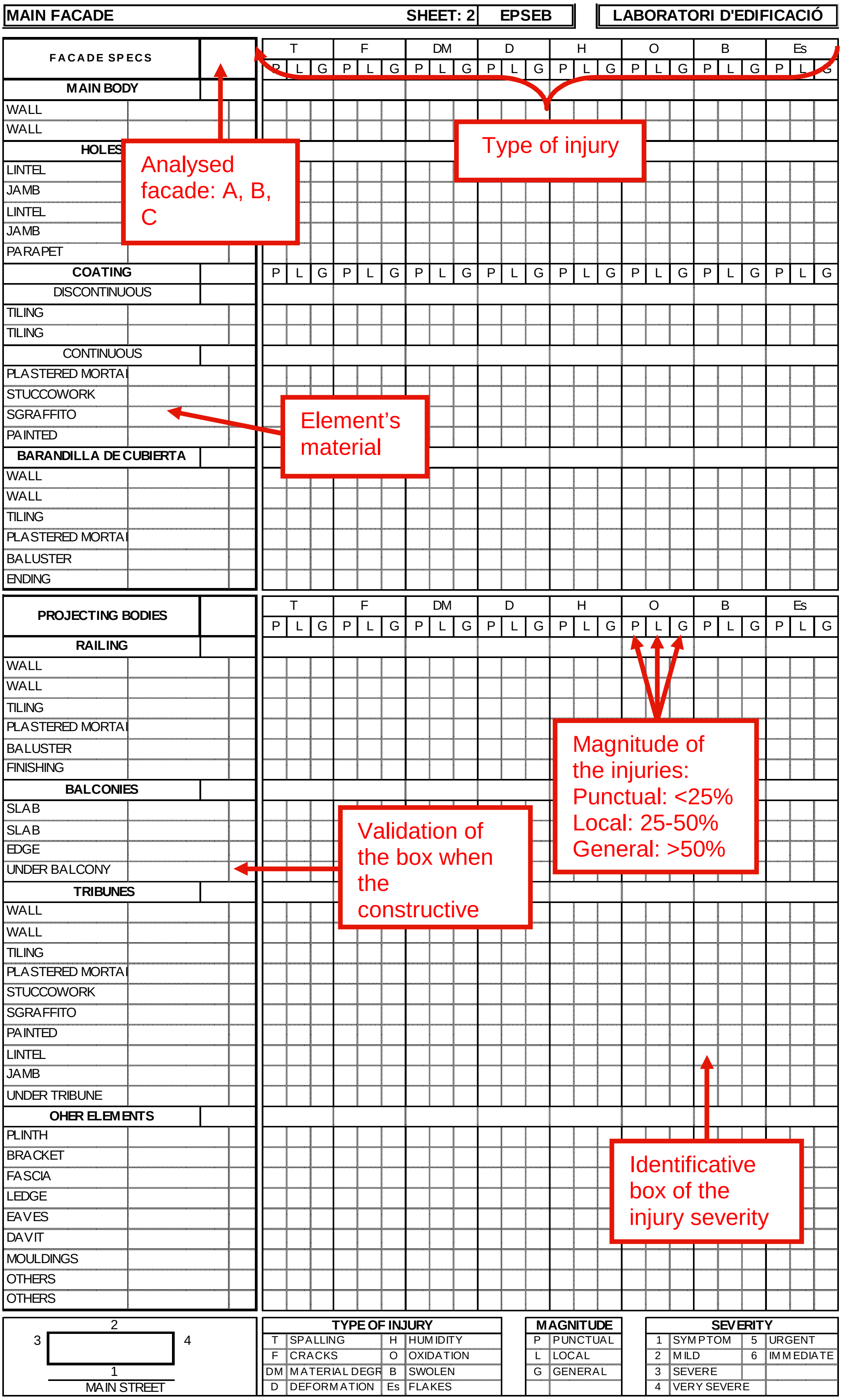


Figure 3.4a: specific information sheet Adapted from: Gibert-Royano 2010

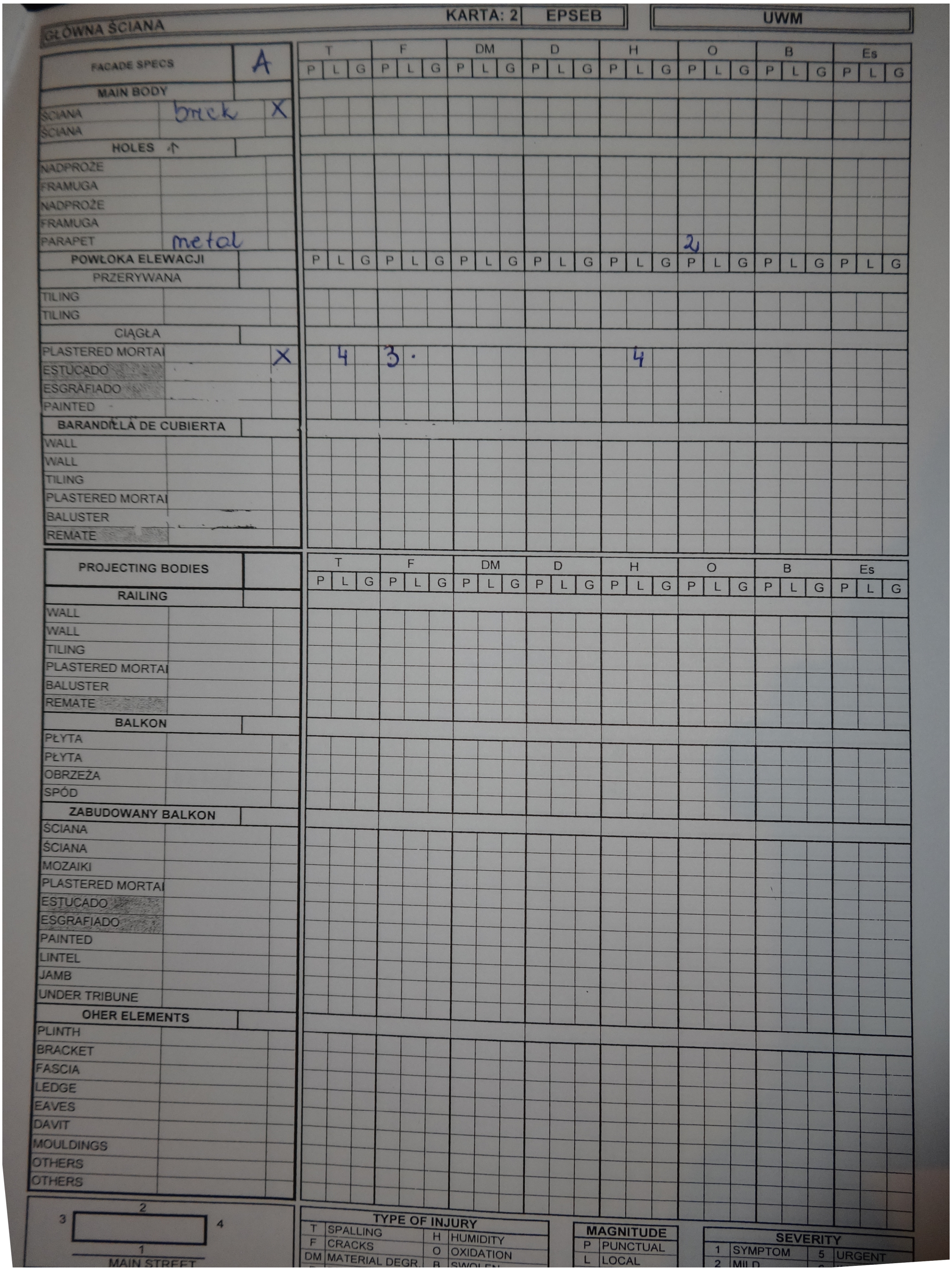

GŁÓWNA ŚCIANA
KARTA: 2 EPSEB
UWM
FACADE SPECS A
T F DM D H O B Es
P L G
MAIN BODY
ŚCIANA brick X
ŚCIANA
HOLES
NADPROŻE
FRAMUGA
NADPROŻE
FRAMUGA
PARAPET metal
POWŁOKA ELEWACJI
PRZERYWANA
TILING
TILING
CIĄGŁA
PLASTERED MORTAI X
ESTUCADO
ESGRAFIADO
PAINTED
BARANDILLA DE CUBIERTA
WALL
WALL
TILING
PLASTERED MORTAI
BALUSTER
REMATE
PROJECTING BODIES
RAILING
WALL
WALL
TILING
PLASTERED MORTAI
BALUSTER
REMATE
BALKON
PŁYTA
PŁYTA
OBRZEŻA
SPÓD
ZABUDOWANY BALKON
ŚCIANA
ŚCIANA
MOZAIKI
PLASTERED MORTAI
ESTUCADO
ESGRAFIADO
PAINTED
LINTEL
JAMB
UNDER TRIBUNE
OHER ELEMENTS
PLINTH
BRACKET
FASCIA
LEDGE
EAVES
DAVIT
MOULDINGS
OTHERS
OTHERS
MAIN STREET
TYPE OF INJURY
T SPALLING
F CRACKS
DM MATERIAL DEGR.
H HUMIDITY
O OXIDATION
MAGNITUDE
P PUNCTUAL
L LOCAL
SEVERITY
1 SYMPTOM
5 URGENT

Figure 3.4b: specific information. Example

4 PROPOSAL FOR RELIABILITY ANALYSIS TECHNIQUES IN BUILDINGS

4.1 Introduction

The construction sector has traditionally been based on behavioral parameters of what is built based on the experience of experts master builders. These construction methods are sustained in experimental models that gave good results over time, but without scientific justification which vouch for his goodness, and its universal application as generalists systems.

The purpose of this section is to introduce the understanding of analysis techniques for knowledge of the life of those structural elements that interfere directly in the durability of a building.

For the realization of this work have been consulted and extracted concepts from studies carried out in the final draft career Technical Architecture student Susana Martin Escribano (2004) regarding the *"Analysis of time to injury in existing facades and severity, characterization and prediction, in the case of the courtyards of l'Eixample ",* and Juan Pedro

Liébana Olmo and Javier Molons Galobardes (2005) work *" Development of a platform for durability analysis of injury facades applied in Santiago and Valparaiso in Chile"* and the detailed specific bibliography in Chapter II - State of the question. These projects were conducted under the direction of Dr. Carles Serrat i Piè and Professor Vicente Gibert i Armengol.

4.2 The concept of building durability

According to the International Organization for Standardization (ISO) quality is the set of properties and characteristics of a product giving it the aptitude to satisfy stated and implied needs. In the case of a building, needs to be satisfied are, among some others, safety, durability, functionality (implicit) and any express need property (explicit).

The quality, safety and durability of a building, construction element or materials are related because durability is a need for the buildings and is intimately linked to sustainability.

The durability and reliability is the ability of a construction element, material or construction, as considered, to perform its function under stated conditions for a specified period of time.

In practice, the durability must be measured statistically, because the same elements have different durability. If you have two identical household appliances characteristics and under equal conditions of use, the performance of the two will not be the same, one fail before the other, so durability is variable from one individual to another and this phenomenon can be measured statistically. You cannot know in advance the exact moment when the failure will occur, therefore this time is a random variable and must be treated with tools of probability.

The probabilistic language accepts a quantitative definition of durability as the probability that a product to perform its function under conditions and time period established.

A building is considered the construction finale product, but is the result of a constructive process that integrates various subsystems including foundation, structure, walls, finishes, etc. These subsystems, at the same time are formed by different elements that work together in a constructive model, eg reinforced concrete pillars and unidirectional frameworks. And finally, these structural elements are formed by a set of materials, or other items that can be processed on site, semifinished or prefabricated.

The conditions set for the use of a building includes the requirements previously defined by property, execution project author, mandatory rules, etc., as well as conditions such as: seismic degree of site, climatology etc. When building a set of different components, conditions of use, must also be set for different parts and processes of the work. Therefore, for a construction element or materials, there are conditions under which they must perform their function.

As a material and its use in construction affect the durability of the construction element of which are part, this element will affect the subsystem and the building construction system, therefore the durability of the building.

When a product is created experimentally and is manufactured in series, like most materials used in the work (brick, corrugated steel bars, etc.), you can check its durability, undergoing tests and trials prior to their mass production. These tests must involve verifying the durability and simultaneously must be representative to evaluate the units subsequently performed. Simultaneously a system of rules to follow during manufacture, transport, reception and exploitation to maintain its durability is made. These tests or experiments are called tests of life, life tests or tests of reliability or durability.

In other materials and construction elements that are made "in situ" is not possible to perform tests of life during their design, as they are unique products, but in executing the work, tests and integrated into quality control inspections.

Tests and trials of life to the controls that determine the durability of a product, the probability to continue operating at a given time, are to be considered. The tests that determine characteristics such as strength, yield strength, etc. are not evidence of life, although these impact durability.

The failure is the fundamental notion of durability and is understood as to the ability of an item to perform its function. Is the fundamental concept because if the failure is not produced, it would make no sense to study the durability. If there is not an injury the study of time without it has no point.

The failure mode is the way in which the failure is observed as failure mechanism is the physical, chemical or otherwise process, that causes the failure . In some cases this clearly occurs, for example, if we make the study of a light bulb, this works when illuminate if does not illuminate is not working and failure is produced. In a constructive element the failure is not shown so clearly for two reasons: an element usually has various functions such as a façade whose functions: sealing, insulation, security, esthetics, etc. May be considered the goal of one of the functions is the failure of the element, but can also be seen that the element fails if the end of all functions occurs. At the same time, the end of these functions is shown either naturally, that means that, ¿From what magnitude the presence of moisture on a facade is considered as a failure of the seal? Must be defined accurately from which magnitude is considered the failure. This way should be observed the magnitude of humidity and define an upper tolerance limit for the observed value. When the limit is exceeded, the failure is produced.

Therefore, it is essential to define what is meant by failure of a component.

When the failure is defined as a certain level of degradation of an element, is an artificial concept that simplifies the durability study where the failure takes a long time to occur.

Thus, the existence of a crack in a facade in a certain degree of security risk for people is an artificial definition of failure. The failure is displayed naturally when the detachment of part of the facade occurs. When the failure takes too long to occur, consider the durability of an element in terms of failure is not possible. In these cases, the solution is to study the variation and evolution through time of a particular property in which degradation occurs over time. Performing various inspections, different observations are obtained, resulting in a degradation curve for each individual in the sample.

The cause of failure is the group of circumstances to which is exposed an element that causes a dysfunction in it. May be project errors, runtime errors, poor quality of materials, maintenance, other injury and a combination of several of the above causes.

An injury is the manifestation of a constructive problem. The construction has a startup problem, that means that, a cause, an evolution (pathological process) and a manifestation (injury). Considering the existence of an injury as the failure, the cause is defined as the immediate origin of the pathological process. Depending on the nature of the causes can be performed variousfailure classifications.

It can be distinguished between extrinsic cause to the element failures, called misuse intrinsic failure, and failure of intrinsic cause, called inherent weakness failure.

Pathological processes occurring in the buildings components, in most cases, are caused by the combination of different circumstances. The basic classification of them is based on whether they are alone capable of causing or not the process. The direct causes (by themselves originate the failure) are often inherent to the item and indirect causes (they need a direct cause) are usually project or execution errors.

Therefore by being the majority of injuries caused by the combination of several causes cannot make a classification of the lesion as a single casuistry. Instead you can make a classification when it is direct.

Another fundamental classification in analysis durability, is the primary failure, which is not caused neither directly nor indirectly by another failure, and the secondary which is caused by another element failure. The identification and classification of causes of an injury belongs to the competent technician. In this study the starting point is some inspections, in which are determined the existence of injuries (failures) in a given time, but not is performed a pathological opinion which determine the causes of the failures. Therefore one can not ascertain if the causes affect the durability of the facade.

As a result of the study, it may be obtained if the existence of injury depends on a factor, but we will not say with certainty that this factor is the cause of the origin of the pathological process. That is, it is possible to analyze if the existence of an injury, or more, in the element somehow influences the appearance of another injury (multivariate analysis).

The failure due to wear (wear-out failure) is the failure with a probability of occurrence increasing with the passing of time. These failures of the slow and progressive variation called aging or wear of the parameters that determine the quality is attributed to the element.

Based on the above it is necessary to establish which are the characteristics of durability, its mathematical foundations, the half life of an element and its experimental values as well as the durability estimations with confidence intervals, failure rates and types of risk functions.

4.3 Key concepts

The quantitative definition of durability, as mentioned previously is the probability associated with a operating time. It is a function that associates to each time t a probability which we call $R(t)$. If T is the random variable which describes the time until failure, $R(t)$ is defined as

$$R(t) = P(T > t)$$

So, $R(t)$ is the probability that an individual will survive longer than t, or what is the same, the probability of failing after t (or in other words, that has not failed before t)

This probability distribution can be characterized by some **statistics** which in the context of durability are called **durability characteristics**.

The constructive elements of a building can be, mostly, intervened to remedy the presence of an injury, a failure. It can be done a study of the time to failure and then ignoring the individuals who have failed, or, you can also consider the intervention of the elements that have failed and do the study between consecutive failures

This distribution and durability characteristics have a different meaning depending on whether the elements submitted to an intervention that repairs the failure or injury, intervened elements, or elements that do not undergo such intervention, not intervened elements. In items that are not intervened, is considered the elapsed time until failure and the variation from one individual to another gives us a distribution object of study of the durability of this element. If the elements are intervened, it also makes sense to consider the time between consecutive failures. The study of the durability is more complicated in this caseexcept where the probability distribution of the time between failures is independent of the age of the element.

Some examples of durability features are: the **average life**, **failure rate**, **durability** at a given time, etc. Durability characteristics are part of the quality characteristics of an element, as they satisfy the operational need for a determined time.

So there are structural elements that require some minimum requirements of the regional legislation and central to consumer protection and are properties that influence the durability of elements such as compressive strength, steel coatings, etc., in the structural concrete case.

In these cases it must meet and demonstrate, at all levels of production since the building is the integration of various products. So, they should be ensured by the supplier, subcontractor, contractor, etc., by certified of recognized quality or by performing inspections or tests required, to comply with mandatory documentation.

There are other consignments of elements that are controlled in the reception phase or execution, and that are not legislated but that may require the property in the construction contract.

These requirements are influencing the durability of the elements, but they are not known and no test is performed to confirm any characteristic of durability. Therefore, it can not give any performance warranty, while the guaranty given by a manufacturer is based, generally, on their durability characteristics.

Por experiencia se dispone de un valor muy aproximado de estos parámetros, por ello es muy importante concretar de qué forma se obtienen las características de durabilidad y la definición de un lenguaje preciso que evite interpretaciones erróneas.

It is very important to note that for the majority of construction products there has not been performed a study based on its life, and durability characteristics are unknown, it is observed only by evidence that certain properties in the product affect the durability of it.

The parameters of durability of an element are theoretical and fixed values, and it is not possible to obtain them empirically. This is because for each sample, different durability characteristics are obtained. If many samples are tested, it is observed that the values of these characteristics are similar but differ from one sample to another, therefore are an approximation, an estimate of the parameter value with their corresponding variability.

In the case of an element not intervened, is named life to the elapsed time until failure. It is noteworthy that the life of an item is considered a random variable, which takes different values for different elements. The average life (mean life) is the average value of the statistical distribution of this variable. It is designated by the letter θ.

The mean life observed is obtained by averaging the lives of all elements of the sample used.

$\theta = \frac{v_1 + v_2 + ... + v_n}{n}$, being $v_1 ... v_n =$ lives of the n elements of the sample

$n =$ number of the elements of the test

For the experimental values of the mean life it can be considered four different versions, as a characteristic of a distribution of durability.

Example:

Let us assume a sample of element subjected to failure test with a total duration of 75 months. The following table shows the times obtained.

Time (months)	Observed failure
20	Yes
56	Yes
45	Yes
75	No
75	No

Table 4.1: Time until failure. *Adapted from: Gibert-Royano 2010*

On the assumption that the sample react according to Table 4.1 based on the times obtained and the observed failures, we would say that the data is complete when all failures are observed. Instead, as in this case, the data are incomplete, since all the times are not known unitl the failure, it is created a situation that although is usual in durability studies, it's distinguished from classical statistical analysis.

A first approximation to the mean life of the product would average the time of failure that have been observed (only 3) and would obtain an estimate of (20 + 56 + 45) / 3 = 40.33 months. Note that this estimate does not take into account the time data corresponding to units that have not failed.

However, if we calculated a observed mean life we would get:

θ =(20+56+45+75+75)/5= 54.2 months.

Note that this estimation still underestimates the mean life in the sense that assumes that the two units that have not failed at the end of the test, they do after 75 months when the actual value is greater.

The **mean time to failure**, MTTF, is a feature of durability applicable to not intervened elements.

The MTTF, although it looks like the mean life, has a different experimental base. As previously mentioned, the mean life observed is the average of the lives of all elements of the sample, however, the observed MTTF is obtained from the ratio of the total time on test (T) (sum of operating times of the elements of the sample) by the number of observed failures. Not necessary to observe the failure of all elements of the sample; this is the reason why this second procedure is followed.

The MTTF is an approximation to the mean life when the statistical distribution of the failure time can be described approximately by an exponential model.

$\mathrm{MTTF} = \frac{T}{n}$, being $T = \Sigma$ of all the times of the elements at test

$n =$ number of observed failure in the test

Following the example:

MTTF= (20+56+45+75+75)/3= 90.33 months

As already mentioned, the mean life observed considers that the two individuals, who have not failed at the end of the test, fail after the 75 months. Instead, the MTTF considers that the two individuals do not fail and their life is greater than 75 months (the denominator is 3 not 5) thus the estimated value is higher and so unbiased estimates the lifetime parameter.

Note that MTTF matches with the observed mean life in the case of dispose of complete samples of time failures observation. The bias produced by the mean life observed in the case of tests with incomplete data (without observing) implies that it is not an appropriate estimator in these tests. To perform the approximation by the observed mean life the duration of the test should last until the failure of the last individual.

The parameters of durability are theoretical values, fixed, but in reality what is possessed is a set of experimental data and what is intended is to obtain, from the data, an estimated value of theoretical parameters.

The **failure rate**, also known as quota failure, represents the proportion of units of a product that fails per unit of time. It is a characteristic of durability that can be interpreted as the "speed" at which failures occur. It is a fundamental concept in the theory of durability, because it allows to describe the evolution of the number of failures. In particular, the hypothesis of constant failure rate over the life of an element simplifies the methodology to be applied.

When the failure rate it's depending on time t it is designed by $h(t)$ and it is named **hazard function**. The expression *λ(t)* is also used to design the hazard function, althought we will use only $h(t)$.

The failure rate is a reciprocal magnitude of the mean life, since the rate is the average number of failures per unit time, and life is a mean time by failure.

For a time interval of t_1 to t_2, the true failure rate, is defined as:

$$h(t_1,t_2) = \frac{[R(t_1) - R(t_2)]/R(t_1)}{t_2 - t_1} = \frac{R(t_1) - R(t_2)}{(t_2 - t_1)R(t_1)}$$

Where, the durability is $R(t)$ the fraction of the survivors at the instant t and $[R(t_1) - R(t_2)]/R(t_1)$ represents de proportion of elements whom not having failed at time t_1, the fail in the range from t_1 to t_2.

When t_2 tends to $t_1(t_2 \to t_1)$ and the lenght of the interval is reduced, is obtained as limit the **instantaneous rate of failure**. Expressed mathematically, is a derivative:

$$h(t) = \lim_{t_2 \to t_1} \frac{R(t_1) - R(t_2)}{t_2 - t_1} = -\frac{R'(t)}{R(t)} = -\frac{1}{R(t_1)} \lim_{t_2 \to t_1} \frac{R(t_1) - R(t_2)}{t_2 - t_1}$$

If it can be assumed that $h(t)$ is independent from t, so, that the failure rate is the same regardless of the element's age, the durability treatment of an element is much easier, as discussed below. In this case $h(t)$ will have a fixed value λ, from which we may obtain an approximate value from the observed data of a sample of an element. In this case, λ is thel reciprocal of the mean life δ :

$$\lambda = \frac{1}{\delta}$$

The instant hazard, $h(t)$, can be expressed as:

$$\begin{cases} R(t) = 1 - F(t) \\ R'(t) = -F'(t) = -f(t) \end{cases}$$

$$h(t) = -\frac{R'(t)}{R(t)} = \frac{f(t)}{R(t)}$$

From the above expression of instant hazard can be deduced the **cumulative hazard**, $H(t)$ (or cumulative failure rate):

$$H(t) = \int_0^t h(s)\,\mathrm{ds}$$

$$H'(t) = h(t) = \frac{f(t)}{R(t)} = -\frac{R'(t)}{R(t)} = [-\ln R(t)]'$$

$$H(t) = -\ln R(t)$$

So the relation between the durability, $R(t)$, and the cumulative hazard, $H(t)$, is the following:

$$R(t) = e^{-H(t)}$$

The simplest case of occurrence of failures is the the one with an element with constant failure rate. In this you can obtain a statistical approximation of life of the element with a simple methodology. In most cases this is not possible because the failure rate can grow over a period of life, and another may decrease. In these cases you can divide the life of the product in these different stages, in which these simple approximations are acceptable.

In the majority of cases, experience has shown that a three-stage scheme is satisfactory. In many cases the duration of one of the stages can be very short, and decide to be ignored, or, you can focus the study on one side and ignore the other.

These three stages are:

a) Early failure period.

Is the period at the beginning of life, during which the failure rate decreases with time. This period is eventual, ie, it is not generally its presence in the life of the products.

In the field of construction, this may be because to there are common execution errors in products and this causes this failure rate so high at the beginning of life. By occurring the failures of the defective individuals, the failure rate decreases, so the velocity of the failures decreases.

b) Constant failure rate period

This is the period with approximately constant failure rate. It is the stage in which you can avoid the wear suffered by the element, because it is very small.

c) Wear-out failure period

The failure rate increases over time. The element enters into a period in which begins to suffer wear.

This segmentation can be illustrated with a graph of the hazard function $h(t)$ of an ideal product, in which the three periods have comparable durations and take place in the order described above in Figure 4.1. This graph is called bathtub curve.

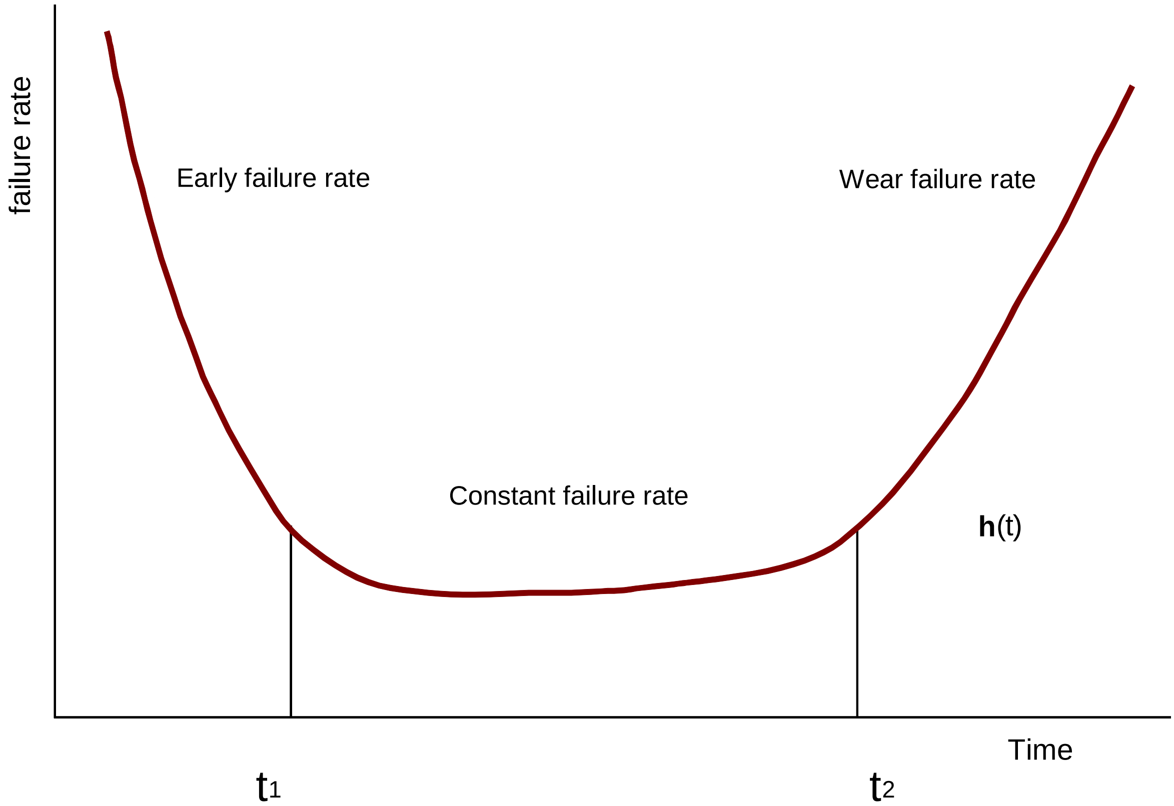


Figure 4.1: Bathub curve Source: Gibert-Royano 2010.

This behavior depends on the product which is treated, not being interesting the whole curve. In practice, in some industrial products it has been considered the hypothesis of constant failure rate when the interest period coincides with the period b) defined before. This is because in some components the durability may be so high that the equipment which will be part will become obsolete before reaching the stage of wear.

In some products, the period of early failure is not part of its commercial life, since production is organized so that this failure will occur within the factory. For that, the device is subjected to an endurance test with the highest stress conditions of use. These tests are called burn-in testing.

In the world of building this type of testing is usually not performed. The buildings are products that undergo long-term obsolescence and is has to be tried by all means their conservation and exploitation by the cost which represents demolition and replacement. Therefore, it should be understood that the elements forming part of it require a surveillance that exceeds the minimum requirements of wear and tear.

It is known from experience that in the construction of new buildings many injuries in the first period after the end of work appear. These failures are usually execution errors and especially are usually given in finishes and are due to weather conditions and an improper planning of the work. These injuries are assumed premature failures. But these trends or assumptions, have no statistical basis. It is necessary to study the durability of the elements, to see if there is a period of early failure in the lives of these. Therefore, it is advisable to create statistical tools, and facilitate the application of these in the world of construction.

4.4 Censored data

The durability analysis is distinct from other statistical techniques because the answers are times, therefore are not measured like the other variables.

Any variable can generally be measured instantaneously, instead durability times can not be measured until failure occurs. The fact that time is measured sequentially has the consequence of censorship. Censorship is given when the information about the durability of some members of the sample is incomplete. This lack of information carries considerable technical problems.

The causes of why censorship occurs are several, giving the case that the study is finished before the failure of the last individual, or because the track of it is lost and therefore, they are not observed during the entire period that lasts the analysis.

In the text it is talked about tests with complete data, that is, tests in which all failures were observed, or tests with incomplete data in which there are failures that have not been observed. The term censored mean the same as incomplete, ie, a lack of information.

Further on concepts for the case where data are not censored will be explained, because the methodology to follow its easier and understandable.

As previously mentioned, depending on whether we observe or not the failures of individuals, the estimators of the durability characteristics are not the same. The same happens when individuals have different type of censorship because of the design of the test. That is, is not the same to set observation intervals than a continuous observation in conducting an essay and, therefore, the censures will not be the same neither the estimators durability characteristics. For this reason it is necessary to study the different censorship.

Censorship is not informative when the knowledge of censoring time of one individual does not provide more information on the future survival of it than the it would have if it had continued in the study. This causes that the censored individuals are at the same risk of future failure than those who have not failed and are not censored. Therefore, these individuals are considered equal and have no risk factors to failure than others.

In our case censorship is not informative, so, the lack of information on individuals is independent of the time when the observation is made (when the inspection is done) that is random.

There are several types of censorship that are based on the type of monitoring that has been performed on the test: the right censoring, the left censoring, censorship in an interval and the double censorship.

Right censoring:

In this study the facades inspections have been performed only once, for each individual and at a random time. In this inspection we look for the presence of a given lesion in a given element, so, for each element and each lesion of the field sheet an observation is made. If the injury is present in the element, the failure has occurred, and if not, if the injury does not exist, the event of interest has not occurred.

If the failure is observed, the time until it is known. If for an individual the failure has not occurred during the course of the test (data collection), the observation is said to be right censored (*Case 2 in Figure 4.2, see end of section*).

So the duration of the test is the time between the birth of the building, or analogously, the birth of the element, and the only inspection or data collenting. Therefore, if during the inspection an item has not failed, it is assumed that the failure will occur from the instant of the inspection onwards, but the specific time is not known and has a lack of information. This will be a right censored data.

The right censoring can occur, depending on the test performed, in some of the following circumstances:

- Ending of the study at a predetermined time. The aim is to draw conclusions about the time to failure from the data collected.

- The monitoring of certain individuals (lost to follow-up) is lost. These individuals are observed only during part of the period of observation for several reasons. The reason for the loss of monitoring should be independent of the failure. This occurs in the case when the observation of individuals is continuous, in this case if an individual is lost for demolition or other cause not know due to performing a single inspection.

- The failure occurs for another cause, different to the ones of our interest. This usually occurs in biomedical studies.

The fixed right censoring occurs when the instant of starting and ending of the study is the same for all individuals and for each individual is only observed if it occurs before a prespecified time which we call C_R.

Generalized right censorship is the more frequent in biomedical studies, and is the one that takes place when individuals enter the study at different times and a C_R date is set, in which the study will be finished.

This is the kind of censorship of the data from our study, since the initial time is variable from one individual to another, but the end is fixed. A good way to work with this data is to rescale the time of initiation of these individuals to zero, since what matters in the study is the period of time, not the initial time.

Then, for an arbitrary individual we observe a pair of random variables (Y, δ).

The variable $Y = \min\{T, C_R\}$, is equal to T which is the time until failure, if it has been observed and ets equal to C_R if the study finishes before the failure occurs.

The variable δ is an indicator that takes the value 1 if the value of T has been observed, so if $Y = T$, and takes the value 0 if the individual has been censored,so, if $Y = C_R$.

$$\delta = \begin{cases} 1 \text{ if } T \leq C_R : \text{not censored data} \\ 0 \text{ if } T > C_R : \text{censored data} \end{cases}$$

-

Left censoring:

A lifetime is considered left censored (C_L) if the failure has occurred before the individual entered the study, as long as the study is conducted by a continuous observation.

In the case that the study is conducted by a single observation, as in our case, censorship by the left occurs if the item fails before the inspection. For these individuals the fact that have failed is known, but as to the exact time T that failed only know $T < C_L$ (*see Case 3 in the Figure 4.2*).

In this project, depending on the observed state of the different elements that form the facade, it was determined the existence or not of an injury and consequently, if there had been a failure or not. That is, if at the time of the inspection the lesion is detected, it is possible to determine that the fault has occurred, however the exact time when the event has occurred is unknown.

Data from the facades obtained from visual inspections, contain only right censored data, if the fault has not occurred, and left censored data, if the fault occurred. This type of data, wherein the updated status of the event is collected in a single inspection, is known as Current status of data.

Interval censoring:

Censorship in an interval occurs when the event of interest can not be observed exactly and only is known to have occurred in a certain time interval.

This occurs in the studies in which the observation is not continuous. A series of specific observations separated by time intervals are performed. These intervals are normally defined in the test plan or protocol inspection, ie are part of the study design.

If a new round of inspections in individuals façade elements was performed again, it would be observed elements on which the lesion is censored in the time interval between the first and the second inspection (*Case 4 in Figure 4.2*).

Double censoring:

The double censorship occurs when the time of interest corresponds to the time between two events, but the times in which have been produced these two events are not known and are censored.

In case of being interested in the time elapsed between two levels of severity of an injury, and being those levels progressive, a first inspection is performed and it is observed in an element an injury with a severity level of 1. When a second inspection is done the same injury is observed, but with a level 2 severity. In this case would be a double censorship data *(case 5 in Figure 4.2).*

On the *Figure 4.2 Summary of the types of censorship in the data*, five cases with different failure observations are displayed, based on two different time moments and which kind of censorship corresponds to each one.

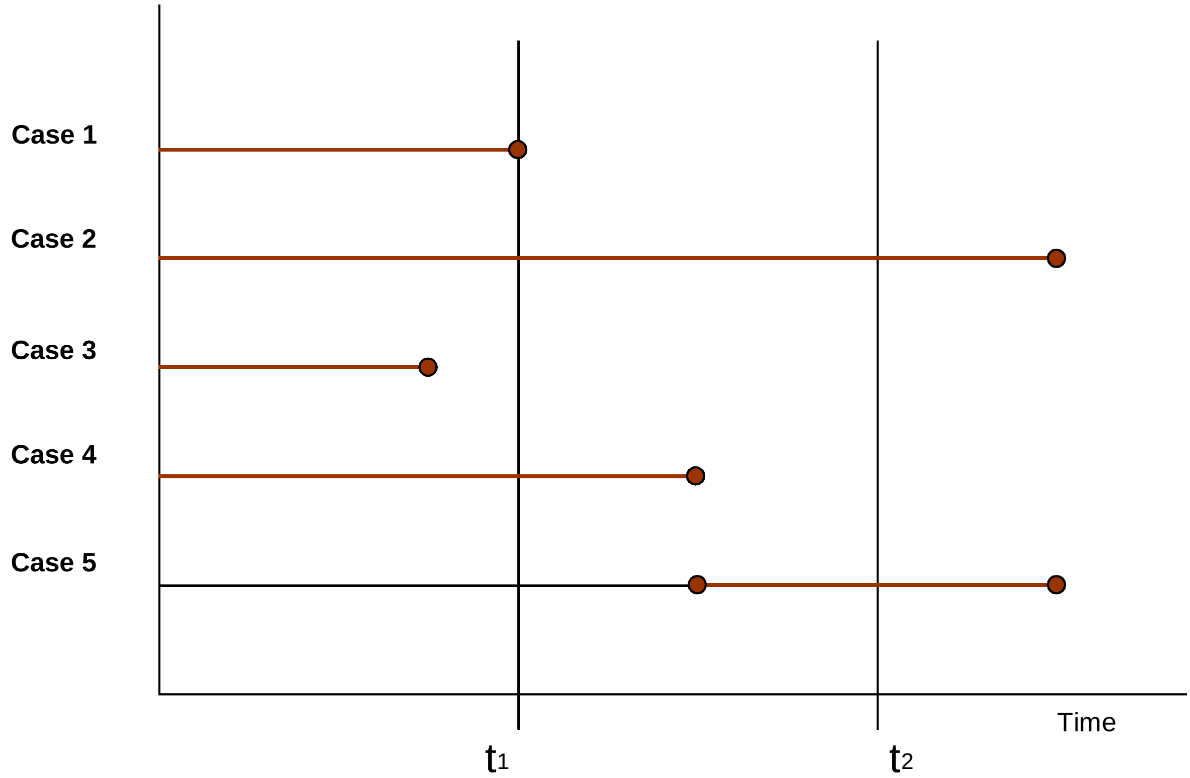


Figure 4.2: Summary of the types of censorship in the data Source: Gibert-Royano 2010

Where:

t1*:* is the time when the first inspection is performed.

t2*:* is the time when the first inspection is performed.

Case 1: it is a non censored data at time t1 (ideal case).

Case 2: it is a right censored data at time t1 and t2

Case 3: it is a left censored data at time t1 and t2

Case 4: it is a data censored in the interval (t1, t2).

Case 5: it is a data with a double censorship (the left end is a data like case 4 and the righ like the case 2).

To further illustrate the concept of censorship applied to the building, in *Figure 4.3* are represented 5 new different cases in which is situated the year of construction of the facade and the two moments when the inspection of checking failures is performed (t1=1950 and t2=1990).

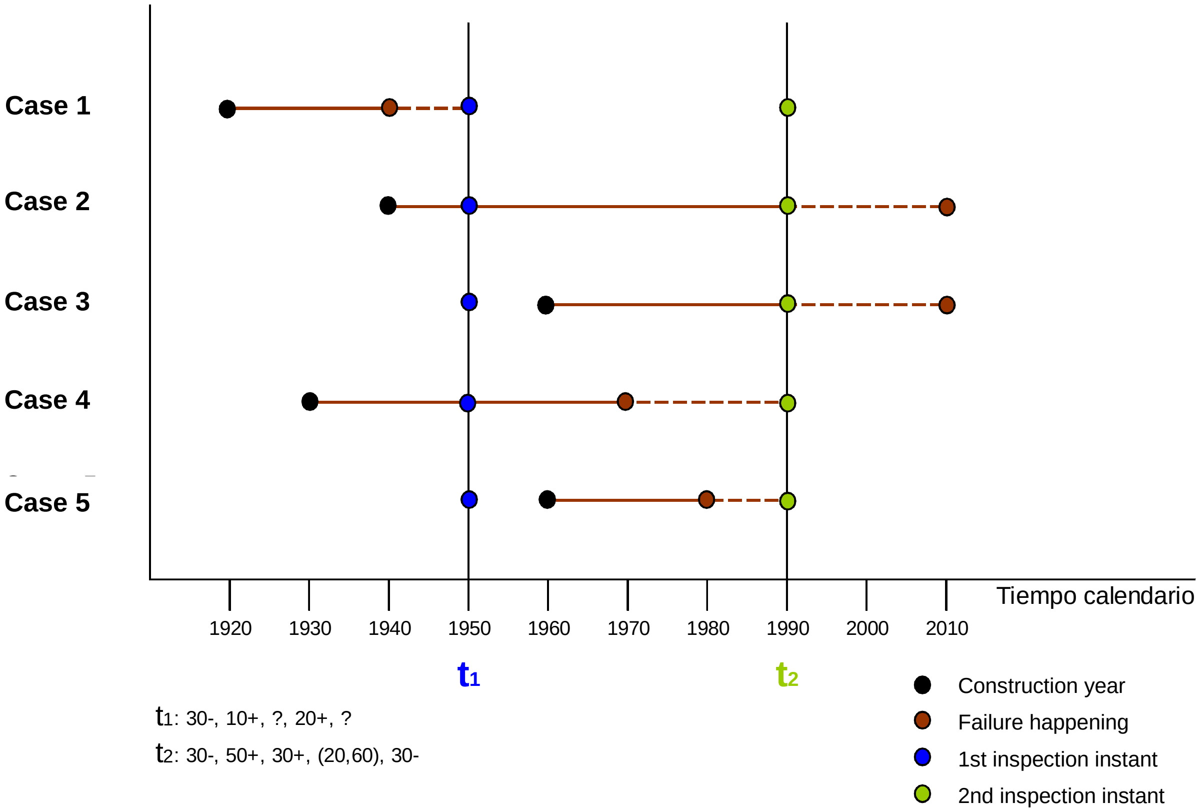


Figure 4.3: Types of censored data (scenario 1). Source: Gibert-Royano 2010

The hypothesis of these new results obtained provides censored information to estimate the probability of failure of the facades.

By analyzing case 1 at time t1 with a rating *(30-)*, it is observed that the individual has already failed and, therefore, all that is known is that the fault has occurred during the period between the date construction of the facade (1920) and 30 years later until the completion of the first inspection (1950). In this case the data obtained from this first inspection are censored by the left.

However, when the case 2 shows at the same instant t1 the valuation shall be *(10+)*, because the individual has not yet failed. Since the façade was built in 1940 and the first inspection was carried out in 1950, we can say that the failure will occur from 10 year of life of the facade. A similar situation occurs in the case 4 with rating *(20+)*. In both cases the data obtained from this first inspection are right censored.

Finally, if the cases 3 and 5 are observed at time t1 valuation can not be estimated (?) Because the individual does not yet exist. This fact prevents to make any prediction about the proband.

In the same *Figure 4.3* it has been represented a second inspection 40 years later at time t2, which provides, in most cases, further information regarding the instant of failure of the facades.

In case 1, we observe that the data obtained in this second inspection are exactly the same as those of the first. In this case, we still have left censored data *(30-).*

The results of the second inspection for case 2 are still censored by the right, however, we have been able to establish a more narrow period of failure, as they have rejected 40 years from the first inspection *(50+).*

In case 3 is revealed an interesting phenomenon that is worth analyzing. As previously mentioned, at time t1 the individual under study does not yet exist and, therefore, it is not possible to estimate the time that will fail. However, at time t2 the individual already has 30 years of life and have not failed. In this case, it has gone from having a few data without information, to have a right censored data *(30+).*

The inspection carried out at time t2 for case 4 provides a data censored at an interval *(20,60)*, since performing this second inspection 40 years after the first, it is observed that the individual has already failed.

Without doubt, the most significant change is observed in case 5, which goes from having data without information, as was the case 3, to left censored data in a relatively short period *(30-)*. This is due to the fact that at the time of the second inspection, the individual not only existed but had also failed, meaning that its failure had occurred in the period between the date of construction and the instant t2.

In order to evaluate the influence of a second inspection in the data obtained, is configured the *Figure 4.4*, displayed below, where the periods in years of the possible failure events are show in the axis of abscissa.

In this new scenario appear from time 0, two lines corresponding to the inspection times carried out and to the information provided for decision-making. This makes it possible to show a comparison between the data obtained from the inspection at time t1 against the performed at t2.

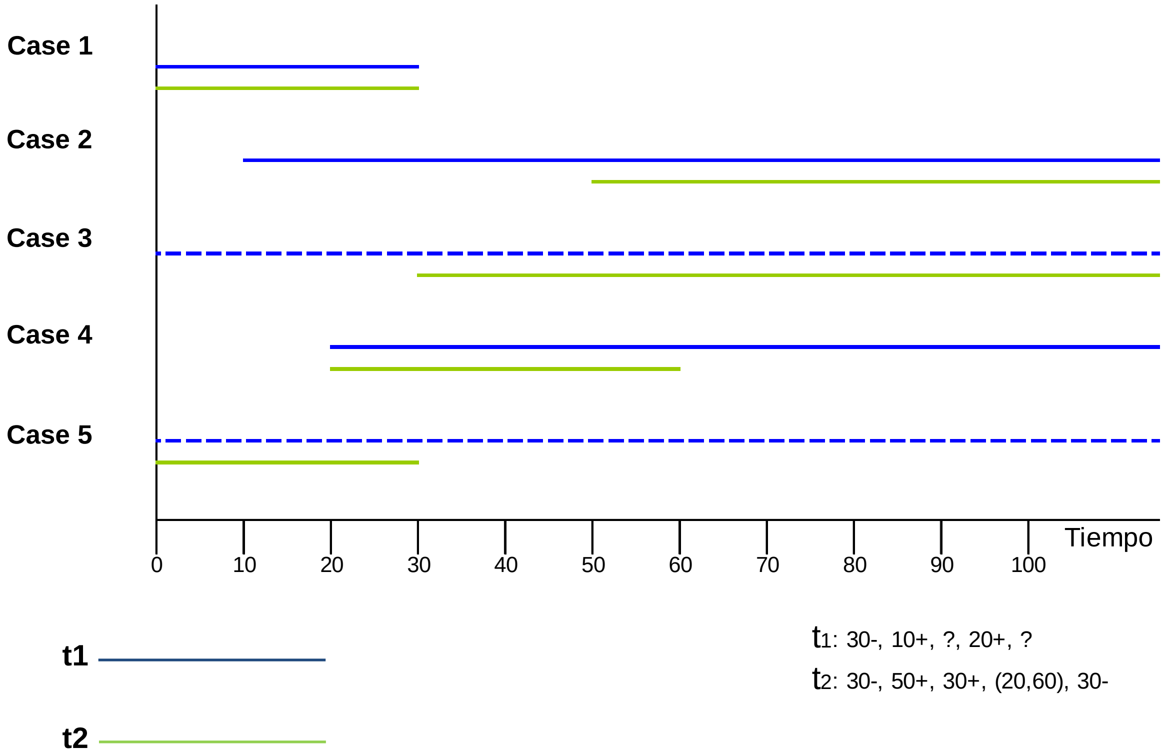


Figure 4.4: Types of censored data (scenario 2)

The above results show that the realization of a second inspection improves, in most cases, the quality of the data obtained, being able to say that based on the studied sample, in the case 1 the failure will occurs before 30 years, in the case 2 after 50 years, in the case 3 after 30 years, in case 4 it failed between the 20 and 60 years, and in case 5 before 30 years.

4.5 Nonparametric approach

The starting data from an analysis of durability are times in which the failure of individuals in a sample occurs. It has been already explained above the concept of how from the initial data, estimators of durability characteristics are obtained.

These estimators or statistical procedures that base all the inference exclusively on information provided by the data, are methods that do not suppose any modeling of themselves and are called non-parametric methods.

But if we are able to assume a certain mathematical-statistical model that fits to the data reasonably well, its distribution function depends on few parameters and provides a more accurate estimation that the ones reached by nonparametric estimation methods. Methods based on data and its adjustment to a theoretical model are termed parametric.

Analysis of the durability of an item to be exhaustive, features a nonparametric first analysis, in which through graphics durability and numerical methods, a first approximate values of the parameters of durability are obtained and are performed as many convenient comparisons, between different gruops of the sample.

After this first analysis, the data adjusting to different parametric models is performed, as well, graphically and numerically. In this project we have chosen to study the behavior of the facades along the time from the point of nonparametric view, since all data obtained from inspections are censored from the right or left, and not information available to validate the goodness of a parametric adjustment.

Then the estimators and nonparametric methods used in the analysis of durability of facades are explained, the subject of this final project.

The estimator of Kaplan and Meieris is used to estimate the durability function in the case that data can be right-censored. In the case that data are censored by the left and/or in a range, the estimation is performed by maximizing the function of nonparametric likelihood.

The distribution function of failure $F(t)$ times, , is the complementary function to the function of durability, $F(t) = 1 - R(t)$ so, , y nos da la probabilidad de fallar antes o igual de un instante dado.

If we construct the likelihood function based on, $F(t)$ we have:

$$L = \prod_{i \in O} (F(o_i) - F(o_i^-)) \prod_{i \in R} (1 - F(r_i)) \prod_{i \in L} F(l_i) \prod_{i \in I} (F(r_i) - F(l_i))$$

Where *O* is the set of observed observations, *R* is the set of right censored observations, *L* is the set of left censored observations, and *I* is the set of interval censored observations.

The expression reflects the contribution of each type of data observed or censored in the likelihood function:

$(F(o_i) - F(o_i^-))$ - , is the failure probability of an observed data at time o_i.

- $(1 - F(r_i))$, is the survival of a data that has not failed at time r_i.

- $F(l_i)$, is the cumulative probability of failure at time l_i, of a left censored data at the moment l_i.

- $(F(r_i) - F(l_i))$, is the probability of failure between times l_i and r_i, for censored in this range data.

Turnbull in 1976 proposes a method for maximizing the above expression that is known as Turnbull estimator. This is an iterative numerical method, according to which the algorithm, after some iterations, converges when the values obtained in these repetitions have no significant differences according to the tolerance defined by the statesman. This maximization is performed considering both left censored, right censored, and interval censored data, and without regarding to any specific parameterization for distribution F.

Turnbull estimator identifies an interval where the probability mass is assigned such that the resulting durability graph is staggered composed of possibly not continuous horizontal segments.

For the case that the times are only either left censored or right censored (current status data), as in this study, the function values of durability estimated by Turnbull correspond to intervals which have as lower end a left censored observation and as the upper end a right censored observation previous to the next left censored.

We must have at least two left censored observations in the data set so that the estimator inform us of durability in two time intervals. In other words, if all the data are only right censored data or a single data left censored, is not possible to identify any length of time and the estimation is not possible.

Particularly if there are only right censorships, one might think that the durability at end of study is 1. This, however, does not mean that after this period no failures of individuals will occur. In this case the time required for a fall in the durability is greater than the study period, and further inspections are necessary in the future

Falls, or variations, of durability, as in the previous case of Kaplan-Meier estimator, will be greater the higher the number of failures or left censored time are in a row.

Although, the Kaplan-Meier estimator for each observed failure produces a jump in the estimation of the durability, in the case of Turnbull estimator, the absence of any observed failure and having only failures censored at the kind of censorship on consecutive times, produces a new estimation interval value but the durability value does not have to change and can be constant over two consecutive intervals. Therefore, the jump in the estimated durability occurs depending on the time distribution of right and left censored, and in general, the greater the accumulation of the same type of censhorship the bigger is the jump.

The last estimated durability interval has as its upper limit the last right censored time and its value does not have to be 0. In case that the last time is a left censored time the upper end of the range estimated is infinite and durability value is 0. This is because there is no right censored data that is greater and indicates that all the individuals have not failed yet.

When is the case of a data series all left censored, the Turnbull estimator estimates from the first left censored time, a single interval with a infinite upper limit. The estimated value is zero, since there is no more time right censored, there are no individuals with a bigger time to fail.

4.6 Implementation of the analysis methodology

Reached this point it is interesting to analyze everything so far explained to set the methodology for determining durability estimators adapted to the existing building, which is the main purpose of this paper. So, we must not forget that the field data used correspond to the observations made in a single inspection, meaning that the information extracted from this inspection will be censured by the left (in the case of injury exists) or to the right (if the injury does not exist).

Since all available data are censored, the analysis to estimate the durability has been performed by nonparametric methods, as these are exclusively based on information provided by the data without assuming any modeling of them.

In this paper has been performed, on the one hand, a univariate analysis of durability and hazard depending on the severity or magnitude of injuries ,and on the other, a multivariate analysis of durability depending on the magnitude of the injuries, both by Turnbull estimator. Multivariate analysis, as discussed in *Chapter V - Application of the model on existing façades*, has allowed to develop up to four curves estimating durability of a given estimator depending on the coexistence or two elements, injury or orientation of the facade.

Another circumstance to be taken into consideration, because it is of vital importance at the time of establishing the sample size and individuals at risk, has been the accumulative view of the lesions observed from the point of view of its magnitude as presenting severity. Thereby, if at the time of making inspection t1 an element of the facade shows a lesion puctual, it is recorded in the database that configures general studies; while a magnitude of local type, not just forms part of the own base, but broadens the basis of the specific injury as an injury to evolve to Local previously has been through a punctual type. The same applies to the magnitude of the general type, which accounts in its database and also extends the local magnitude and, of course, the punctual.

These considerations were taken into account for the different severities showing lesions found on the facades.

In Table 4.5 this cumulative criteria and factors described are incorporated in order to make optimal use of available information is displayed.

FACADE			
Part	Location	Element	Material
KIND OF INJURY			
Magnitude's state	Punctual	Local	General
Severity's state	Long-term	Medium-term	Short-term

Table 4.2: Accumulative criteria used on the injuries record Adapted from: Gibert-Royano 2010

PART II: APPLICATIONS OF THE METHODOLOGY

5 MODEL APPLICATION ON EXISTING FACADES

5.1 Background of the project's sample

As was noted in Part 1 - *Project's theoretical frame*, the data for conducting studies that will be analyzed in this project come from a collaborative study between the Building Laboratory of EPSEB and the city of L 'Hospitalet de Llobregat. Both institutions signed an agreement in 1997 for the creation of a "Cataloging facades with determining its risk factor," and that should have ended the year 2001-2002.

The project was born with many skeptical voices augured that the work was not viable because of its size and pretension. Without going into details, because it is not our goal, say that the project not only concluded in a timely manner, but was able to improve the expectations that were set originally.

Those who have participated in this project, teachers, hall technicians and students of final degree thesis, are especially proud of the achievements among other objectives getting some social improvements that we would like to highlight:

a) The elimination of the potential risk of dropping facade elements to the street avoiding accidents to the citizens.
b) The social awareness of users of the buildings that increased the demand for repairing facades in more than 18% during the time of completion of the project.
c) The knowledge of the actual state of the facades of the entire city and the ability to create effective social welfare policies.

Thanks to all this and to understand the importance of the facts, the project has evolved into an aspect eith most research and knowledge contribution. This puts us in conjunction with the Department of Applied Mathematics and the Institute of Statistics and Applied Mathematics at Edification, ahead of the main objective of this work of create mathematical models that are able to improve prediction based on the data obtained.

In the field of research about the behavior and the apparent condition of large urban areas, carried out within the Laboratory of Building, by the established methodology for conducting inspections, the ultimate goal was to determine if possible establish a direct relationship between the state of degradation in which are the facades of buildings with respect to other subsystems that compose it. For this, a first step was to clear up questions of how to assess the state of the facades beyond simple visual observation of their degradation.

Mention that this relationship hadn't been accomplished yet because the information available from the facades was purely descriptive and was not available of any analytical model that allowed to model and justify the results found, much less that these could be representative of the general condition of the building on the other hand further expanding the verification information in other subsystems, such as might be its structure, only added more data accumulation that hardly we would know how to link.

Located on this issue and after fulfilling the project program conducted by the municipality of Hospitalet de Llobregat, which consisted in eliminating the risk of falling fragments on the public highway, which was the main objective of the commission, the project incorporated many improvements by providing identification and localization of other existing lesions on the facades, as well as their type, magnitude and severity, as has been noted in Chapter III - Design for data collection and more precisely in the data collection methodology. From this point, the research took the logical way of trying to prove if with the information available we would be able to establish some sufficiently robust estimators to determine the durability of all the elements inspected or, in other words, which could be their hope of life over time.

Currently, the research line about the study of large urban areas has a database of 21,175 inspected facades made at different times and cities worldwide. This is not the result of chance, it has been done intentionally to provide sufficient data to contrast if the estimates of durability may be general or applicable only in the city that will be taken as experimental.

From the information available it was possible to test that all inspected facades, regardless of the city and the country, based on a quantitative study of them, follow similar standards of conduct against aging and their status. With these data, it has been established what kind of action is necessary to perform for their suitability. In this sense, the graphics displayed of all the found results, we see that the short-term actions are ranging between 6 and 26% , in the medium term results vary between 43 and 63%, and in long-term between 16 and 50% (depending on the city analyzed). This information represents the whole sample and the results are hardly encouraging, as they show that over 47% of the inspected Park is in need of repairs with some urgency. The economic investment which would represent the adequacy and unworkable is multimillionaire with both public and private investment.

This first approach to urban parks inspected reinforces our view that with the implementation of maintenance programs, this situation would not be so alarming but for this would have been necessary to know what preventive measures can be made based on knowledge of assessment degradation over time and how to anticipate the existing impairment.

In *Tables 5.1* the chosen cities and areas of application are represented, and the number of inspected facades quantified. In all of them the systematic and protocol data collection has been the same as discussed in Chapter III, which specifies the design of field data collection and their reasons are justified.

<table>
<tr><th colspan="7">TOTAL SIZE OF THE SAMPLE</th></tr>
<tr><th rowspan="3">COUNTRY</th><th rowspan="3">CITY</th><th rowspan="3">Nº OF INSPECTED FACADES</th><th colspan="3">ACTIONS TO BE TAKEN</th></tr>
<tr><th>Long Term</th><th>Mid term</th><th>Short term</th></tr>
<tr><th>0-1-2</th><th>3-4</th><th>5-6</th></tr>
<tr><td rowspan="19">SPAIN</td><td rowspan="19">L'HOSPITALET DE LLOBREGAT</td><td>1108</td><td>610</td><td>781</td><td>141</td></tr>
<tr><td>946</td><td>464</td><td>446</td><td>36</td></tr>
<tr><td>1335</td><td>741</td><td>559</td><td>35</td></tr>
<tr><td>1458</td><td>591</td><td>710</td><td>155</td></tr>
<tr><td>735</td><td rowspan="2">636</td><td rowspan="2">661</td><td rowspan="2">177</td></tr>
<tr><td>739</td></tr>
<tr><td>762</td><td rowspan="2">705</td><td rowspan="2">723</td><td rowspan="2">126</td></tr>
<tr><td>770</td></tr>
<tr><td>376</td><td>210</td><td>163</td><td>3</td></tr>
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<tr><td>429</td><td>217</td><td>189</td><td>23</td></tr>
<tr><td>197</td><td>123</td><td>63</td><td>11</td></tr>
<tr><td>462</td><td>341</td><td>119</td><td>2</td></tr>
<tr><td>741</td><td>270</td><td>361</td><td>110</td></tr>
<tr><td>735</td><td>297</td><td>348</td><td>90</td></tr>
<tr><td>516</td><td>372</td><td>139</td><td>5</td></tr>
<tr><td>684</td><td>402</td><td>241</td><td>41</td></tr>
<tr><td>407</td><td>334</td><td>69</td><td>4</td></tr>
<tr><td>296</td><td>279</td><td>16</td><td>1</td></tr>
<tr><td colspan="2">SUBTOTAL 1</td><td>13193</td><td>6795</td><td>5871</td><td>971</td></tr>
</table>

Table 5.1a: Sample of 'Hospitalet de Llobregat Adapted from: Gibert-Royano 2010

COUNTRY	CITY	Nº OF INSPECTED FACADES	ACTIONS TO BE TAKEN		
			Long Term	Mid term	Short term
			0-1-2	3-4	5-6
SPAIN	ESPORLES (MALLORCA)	291	124	150	17
SUBTOTAL 2		**291**	**124**	**150**	**17**

Table 5.1b: Sample of Esporles (Mallorca) Adapted from: Gibert-Royano 2010

COUNTRY	CITY	Nº OF INSPECTED FACADES	ACTIONS TO BE TAKEN		
			Long Term	Mid term	Short term
			0-1-2	3-4	5-6
SPAIN	BARCELONA (Ciutat Vella)	126	17	16	84
		340	37	174	129
		178	32	91	55
		327	95	88	144
		237	33	143	61
		372	24	326	22
		304	137	164	3
		471	195	200	76
		276	59	196	21
SUBTOTAL 3		**2631**	**629**	**1398**	**595**

Table 5.1c: Sample of Barcelona (Ciutat Vella) Adapted from: Gibert-Royano 2010

COUNTRY	CITY	Nº OF INSPECTED FACADES	ACTIONS TO BE TAKEN		
			Long Term	Mid term	Short term
			0-1-2	3-4	5-6
SPAIN	BARCELONA (Eixample)	378	182	161	35
		387	104	251	32
		250	33	111	106
		407	143	215	49
		412	143	218	51
		366	122	167	17
		209	148	59	2
		327	173	138	16
SUBTOTAL 4		**2736**	**1048**	**1320**	**308**

Table 5.1d: Sample of Barcelona (Eixample) Adapted from: Gibert-Royano 2010

COUNTRY	CITY	Nº OF INSPECTED FACADES	ACTIONS TO BE TAKEN		
			Long Term	Mid term	Short term
			0-1-2	3-4	5-6
CHILE	VALPARAÍSO	396	63	230	103
	SANTIAGO DE CHILE	1403	398	859	146
SUBTOTAL 5		**1799**	**461**	**1089**	**249**

Table 5.1e: Sample of Valparaíso and Santiago de Chile Adapted from: Gibert-Royano 2010

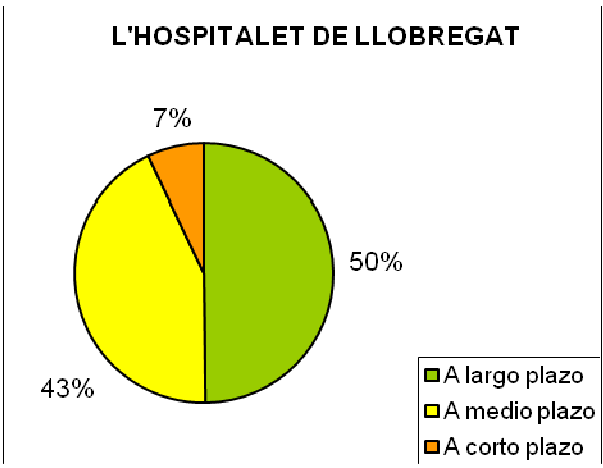
COUNTRY	CITY	Nº OF INSPECTED FACADES	ACTIONS TO BE TAKEN		
			Long Term	Mid term	Short term
			0-1-2	3-4	5-6
MÉXICO	MÉXICO D.F.	384	59	249	76
		141	24	81	36
SUBTOTAL 6		**525**	**83**	**330**	**112**

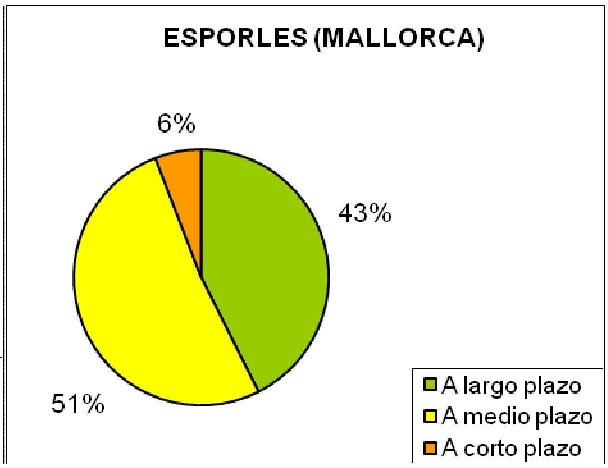
Table 5.1f: Sample of México D.F. Adapted from: Gibert-Royano 2010

TOTAL O INSPECTED FACADES	**21175**	**9140**	**10158**	**2252**

Table 5.1g: Total of inspections performed and intervention proposals Adapted from: Gibert-Royano 2010

To establish more unified parameters regarding the decisions of action, have been grouped together the grades of severity of injuries represented in the tabs inspection 0-1-2 blocks for a proposed long-term performance, severities 3- 4 for the medium term, and 5-6 for short-term proposals. These severities have been linked to an equivalence in time of 10 years for long-term actions of 5-10 years for medium-term actions and finally to 1-5 years for short-term, except gravity 6 it has character immediately and must be removed within 24 to 48 hours. Figure 5.1 shows the percentage of our three divisions for each city and finally inspected the global status of all of them represented.





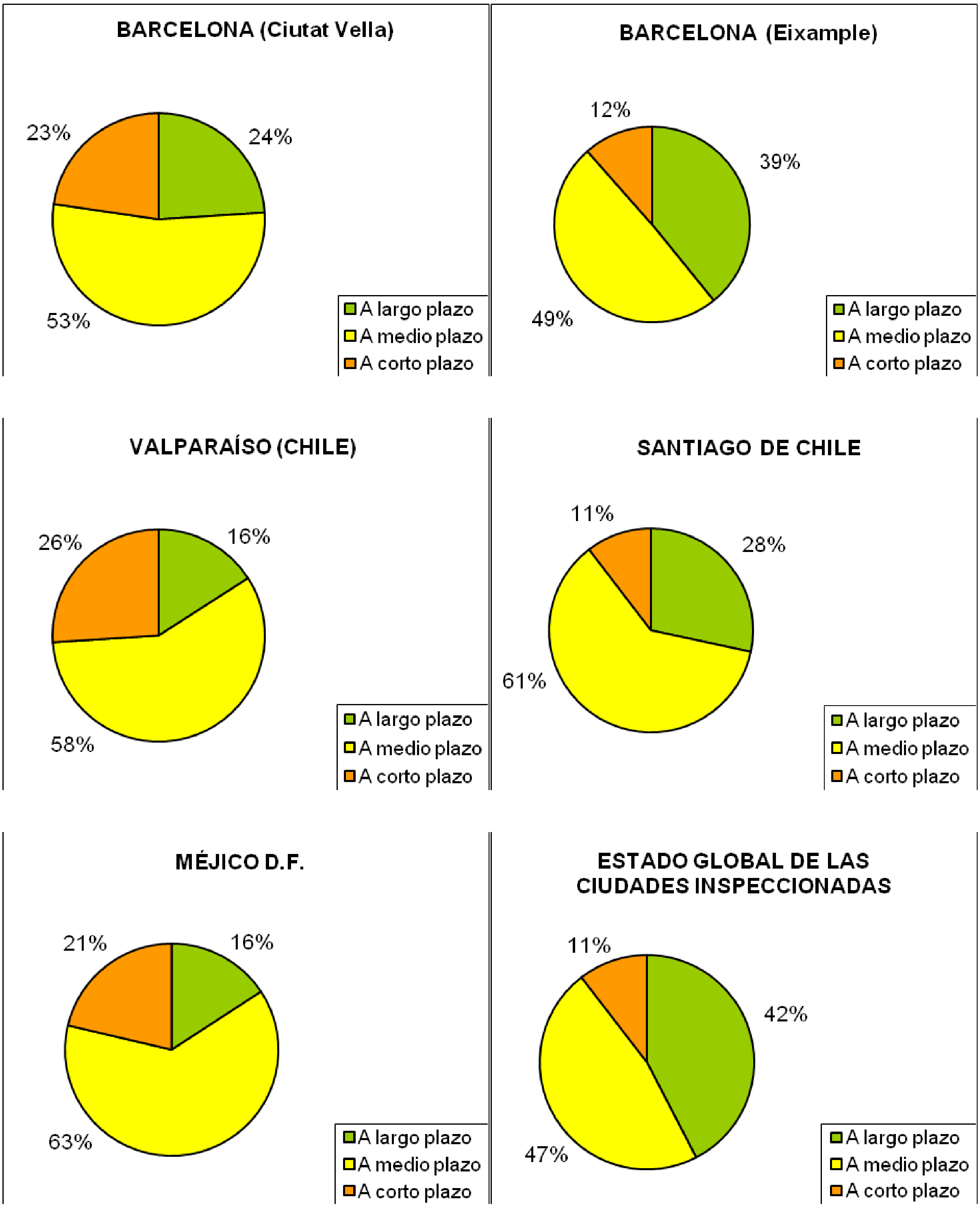


Figure 5.1: Percentages of the state of the facades and their intervention Adapted from: Gibert-Royano 2010

From the performed studies and the data available from each city on inspections of facades on a large scale, the project has chosen the city of Hospitalet de Llobregat as a pattern for the realization of our project for the reasons already argued Chapter I where the purpose of work is defined.

In order to intensify the knowledge of the city we were interested in to know how it came the growth of Hospitalet de Llobregat throughout its history from the urban and constructive point of view. The city has not had a uniform or regular growth, and neither has behaved as a central core in expansion; rather it has started from three active cores around neighbourhoods Centre, Santa Eulalia and Collblanc-Torrassa, which have persecuted look for connections with neighbouring cities rather than each other.

One of the determining factors of such growth has been the strong immigration that has suffered Hospitalet de Llobregat with citizens of the south of Spain, creating originally a dormitory city to the nearest big city of Barcelona.

Without this section wishes to be a comprehensive historical study of the city, as it is not our goal, it has been consulted the Historical Archives of Hospitalet de Llobregat, where thanks to the book "A synthesis of past and future tools" we have extracted the most relevant information to understand from the urbanistic point of view, how it was been developing what today is known as the city of Hospitalet de Llobregat.

The city has an area of 12.5 km^2 located in the flat coastline in the region of Barcelonès. Bordered Barcelona, Esplugues de Llobregat, Cornellà de Llobregat and El Prat de Llobregat, and has a population of 257,038 inhabitants, referring to 01/01/2009 numbers, according to Royal Decree 1918/2009, of December 11 (*Source: Institute of National Statistics*), and its population origin corresponds to 56.2% of Catalonia, 17.8% of Andalusia, Extremadura 4.5%, 4.2% of Castilla y León, Castilla la Mancha 3.7%, Galicia 3.4%, 2.4% of Aragon, Murcia 1.5%, 1.3% from Valencia and 3% outside Spain.

It is from the 1910s to 1919 when the city began to receive strong immigration especially from the provinces of Murcia and Andalusia. This situation will not be stopped until the decade of the 80s.

At the end of the 1950s to 1959 and the beginning of the next, is performed the urban planning of future neighborhoods that developed outside the core of the city. The neighborhoods of the Centre, Santa Eulalia and Collblanc-Torrassa suffer silting of existing solar, while other neighborhoods become urbanized. All this took place within the regulations of the Partial Plans of different sectors.

In the beginning of the project, the town consisted of sixteen districts organized according to *Figure 5.2 Distribution and status of neighborhoods in the city of Hospitalet de Llobregat*, where its geographical location is shown within the village. Currently these territorial distributions have changed or been grouped which have not been taken into consideration by not alter the objective of our work or the sample

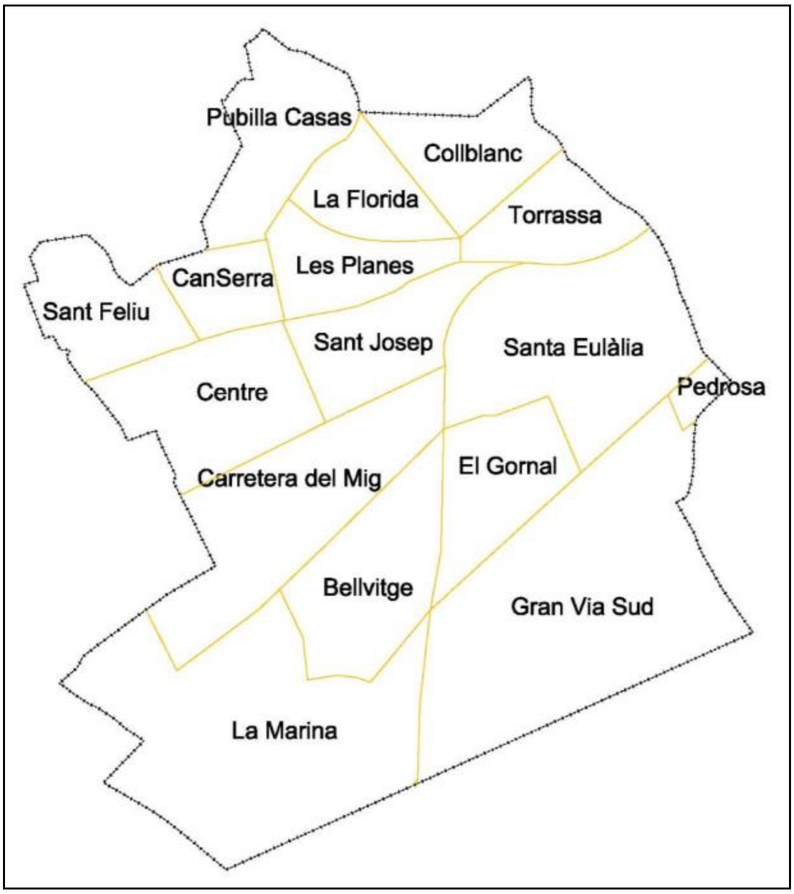


Figure 5.2 Distribution and status of neighborhoods in the city of Hospitalet de Llobregat *Source: Gibert-Royano 2010*

Leaving aside the past interventions of emptying the city, Hospitalet de Llobregat is stagnating in the territorial growth, leaving only the urban possibility of overexploitation in height.

The illogical growth of the city from its neighbouring ends with other cities inwards, has marked the major urban context of the city.

Following a correlation with the time periods which later will be established to study the inspected facades, its have been made some groups subdivided by constructive decades from 1700 to 2000.

Some other information considered of interest is provided by the Municipality of Hospitalet de Llobregat through its website www.lh.cat on land use under the current planning, which shows how the soil is classified, how households are distributed according to the districts and the number of occupied buildings without registration according districts.

According to this information, the residential use has an area of 292 Ha. To evaluate the impact of the affectation of the facades of the buildings in 2008, it is estimated that it affects about 105,650 dwellings in the city, with an average housing occupancy of 3 persons, we are talking about 316,950 citizens.

Año de inspección	Barrio	Nº fachadas inspeccionadas	Tipologia de lesión máxima																										
			Actuación a largo plazo								Actuació a medio plazo								Actuación a corto plazo								A largo plazo	A medio plazo	A corto plazo
			Bufat	Esvoranc	Humitat	Degradació	Deformació	Fisura	Oxidació	Trencat	Bufat	Esvoranc	Humitat	Degradació	Deformació	Fisura	Oxidació	Trencat	Bufat	Esvoranc	Humitat	Degradació	Deformació	Fisura	Oxidació	Trencat			
1998	Collblanc	1449	7	15	67	72	0	218	5	236	143	21	36	91	3	329	18	67	50	0	1	1	3	39	2	25	620	708	121
1998	Florida	946	5	10	36	93	1	176	4	139	123	11	10	36	1	160	7	98	17	0	0	0	0	4	0	14	464	446	36
1998	Pubilla Casas	1335	8	16	57	149	1	281	6	223	155	13	12	45	2	200	9	123	16	0	0	0	0	4	0	14	741	559	35
1998	Torrassa	1290	8	13	31	110	0	215	5	85	292	19	3	54	1	197	10	114	86	0	0	0	1	0	3	43	467	690	133
1999	Santa Eulàlia	731	0	0	4	82	2	65	1	74	61	3	0	0	1	117	1	213	32	0	0	0	0	3	0	72	228	396	107
2000	Centre	1554	3	7	94	82	12	244	18	245	63	13	32	69	19	360	28	139	38	0	0	6	6	46	1	29	705	723	126
2001	Bellvitge - El Gornal	1250	6	11	27	88	6	211	28	293	5	1	15	64	6	238	30	157	2	0	0	1	2	24	1	34	670	516	64
2001	Can Serra	516	3	5	47	21	3	55	5	17	4	9	37	7	1	221	6	37	0	0	0	1	0	23	0	14	156	322	38
2001	Carretera del Mig	1443	1	1	89	31	23	227	8	180	133	0	15	56	27	359	24	81	85	0	0	13	8	50	2	30	560	695	188
2001	Les Planes	684	5	6	79	37	4	143	4	124	12	2	6	1	13	165	6	36	5	0	0	1	3	28	0	4	402	241	41
2001	Sant Josep	698	0	5	58	62	2	70	7	54	13	32	46	58	4	172	12	87	1	1	0	0	1	10	0	3	258	424	16
2002	Gran Via Sud - Pedrosa	128	1	0	8	36	11	13	16	20	1	0	0	4	0	7	0	8	0	0	0	0	0	3	0	0	105	20	3
2002	Sant Feliu	275	0	6	5	8	0	22	1	9	7	21	10	4	0	99	6	48	2	7	0	0	1	14	0	5	51	195	29
TOTALES ACUMULADOS		12299	47	94	603	871	65	1940	108	1699	1012	146	221	489	78	2624	157	1208	334	8	1	23	25	248	10	286	5427	5935	937

Table 5.2: Quantification and classification of injuries and acting proposal Source: Gibert-Royano 2010

Another type of analysis was to establish over the whole sample facades which contributed all the information to be analyzed, to which period corresponded and to which neighborhoods. With all facades selected, tables and graphs were generated, which grouped the facades by building decades, since age could be a factor of their representative state. At the same time, these facades are grouped under the same conditions of impact and the consequent proposed action. This was performed on each of the neighborhoods in order to verify the influence of different decades in the durability of the facades. The following Table 5.3 is presented along with a percentage chart as a sample of the study just described, because all the tables are found in Appendix B of this paper.

Neighbourhoods	Total of inspections	PERCENTAGE OF ACTION FOR DECADES					
		1970-1979					
		LONG TERM		MID TERM		SHORT TERM	
Collblanc	1.449	4,90%		6,28%		1,41%	
Florida	946	10,10%		9,88%		0,80%	
Pubilla Casas	1.335	7,73%		5,83%		0,37%	
Torrassa	1.290	2,78%		3,34%		0,73%	
Santa Eulàlia	731	8,94%		10,02%		2,93%	
Centre	1.554	8,21%		8,42%		1,47%	
Bellvitge - El Gornal	1.250	31,02%	1.182	23,78%	1.220	2,82%	219
Can Serra	516	11,24%		26,55%		3,68%	
Carretera del Mig	1.443	11,04%		13,81%		3,89%	
Les Planes	684	7,16%		6,29%		1,61%	
Sant Josep	698	2,09%		2,25%		0,07%	
Gran Via Sud - Pedrosa	128	6,79%		1,23%		0,00%	
Sant Feliu	275	2,28%	Builidings num.	6,27%	Builidings num.	3,70%	Builidings num.

BUILDINGS TOTAL	1970-1979
	2.621

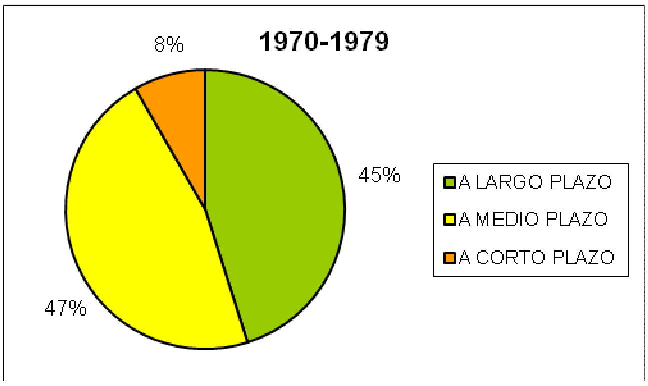


Table 5.3: Percentage of action in 1970-1979 decade source: Gibert-Royano 2010

To evaluate in a global way the *Table 5.3* it has been created *Figure 5.4* which summarizes all the information extracted from other tables in Annex Band that reflects the percentage of injury by severity, translated into actions to adapt long, medium and short term of the entire city.

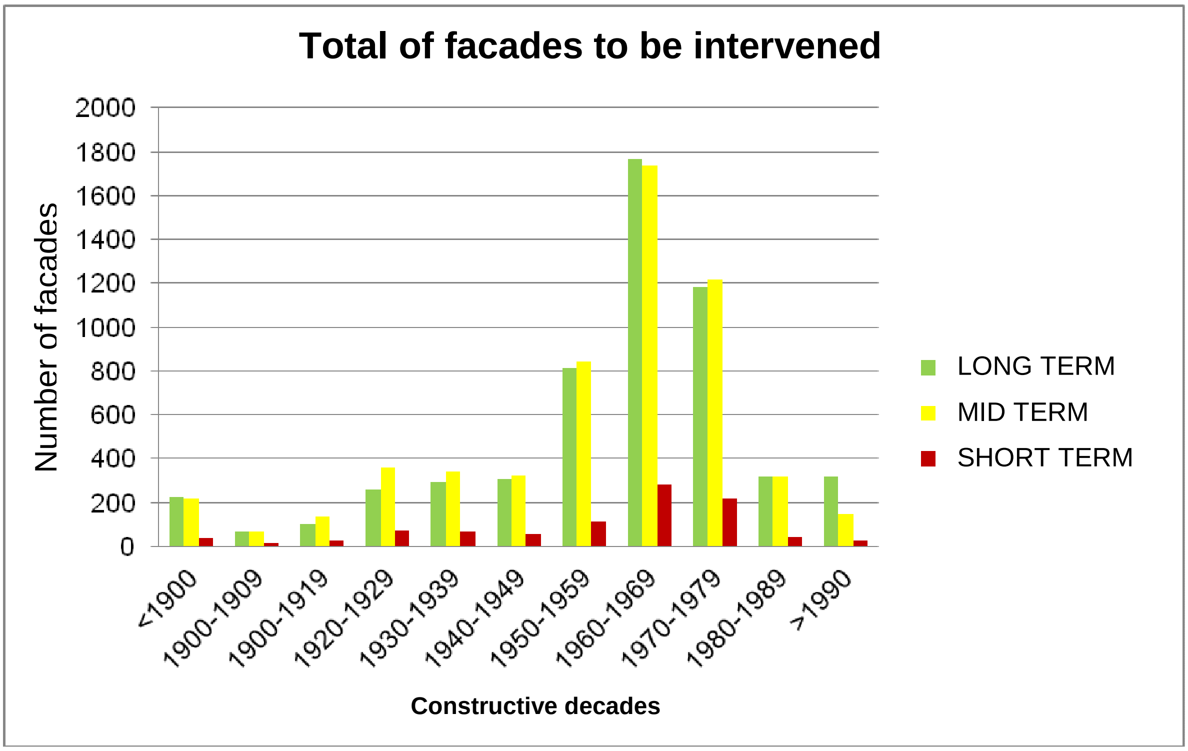


Figure 5.3: Summary graphic of l'Hospitalet de Llobregat Source: Gibert-Royano 2010

This study shows that the age of construction does not seem to be a single factor decisive for the poor condition in which the facades are, as in all decades appear very similar percentages in terms of their degradation. It should be noted the period of the years between the decades 50-60-70 as most critical for the large number of built facades. However, this situation decreases from the 80.

The results extracted do not cease to be quantitative with a significant importance for emergency decision making or for a possibilistic management, however, in our study the aim is go further to be able to demonstrate a more analytical approach that reflects information qualitative that allows us to anticipate events and create preventive policies with greater rationality in public spending.

5.2 Preparation of the sample for the durability analysis

We were aware that both knowledge of the sample as the the functioning of the estimation of Turnbull were essential for understanding the behavior of the function of durability of the facades of Hospitalet de Llobregat.

So, the amount of data in each period is an important determinant of the durability's behavior. This means that although two periods have the same percentage of elements injured, the durability is affected in a period greater than the other, since it falls more or less depending on the number of damaged elements over total elements of any age.

At the start of this study we start from a potential sample of 13,193 facades, that after collating many of them had all the information necessary for the study of durability, was reduced to 10,150 facades.

Given the importance of the distribution of the data by age, the sample of 10,150 facades was taken to determine, based on the date of construction, which individuals could be atypical and if the building mean was an age that was a representative to be studied and if it was balanced. In a first analysis of the entire sample, it was established that the data is subscribed between the years 1,800 and 2,000. The entire sample was studied using a box plot "boxplot" with semi-graphical representation of his distribution to find these outliers. To do this data from low to high were ordered and quartiles and median were calculated. Central resulting box is limited by the lower and upper quartiles (LQ and UQ). Calculating upper and lower allowable limits (LS and LI), which identify outliers are determined by the following expressions:

LS = UQ + 1,5 (UQ-LQ) = UQ + 1,5 IQR
LI = LQ – 1,5 (UQ-LQ) = LQ – 1,5 IQR

Where IQR is the interquartile range.

We will consider outliers which are positioned outside the interval [LI, LS], drawing a line from each of the ends of the central box to farthest value which is not an outlier. We have worked with median values and quartiles because these values are more robust in the presence of outliers.

In Figure 5.6 the boxplot is represented by years of construction after first removing outliers, in which you can see how the data begin to have a more concentrated distribution since

1890. Those data outside the LI and LS limits were eliminated from the study for not affecting durability.

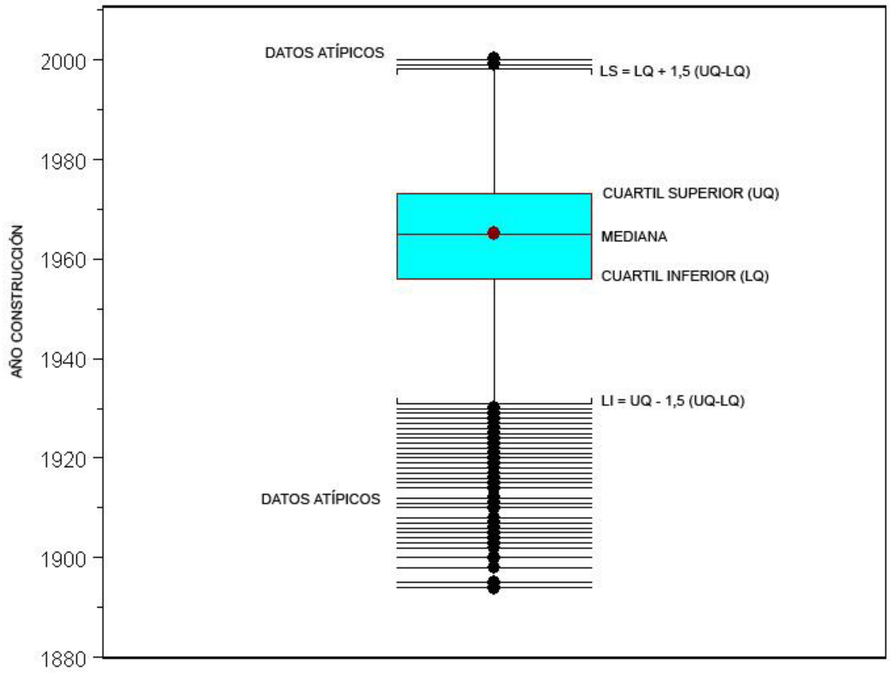


Figure 5.4 Boxplot by year of construction without outliers of the city Hospitalet de Llobregat Source: Gibert-Royano 2010

From the graph in Figure 5.6 is determined that the median age of building facades is set in the year 1965 and therefore sufficient time for the process of injury to be effective.

Despite the existence of data outside the quartiles, we see that the distribution is uniform enough and will accept to continue the study undertaken. The same analysis boxplot for years of construction for each of the districts of the city of Hospitalet de Llobregat was performed. The results of this analysis are shown in Figure 5.7.

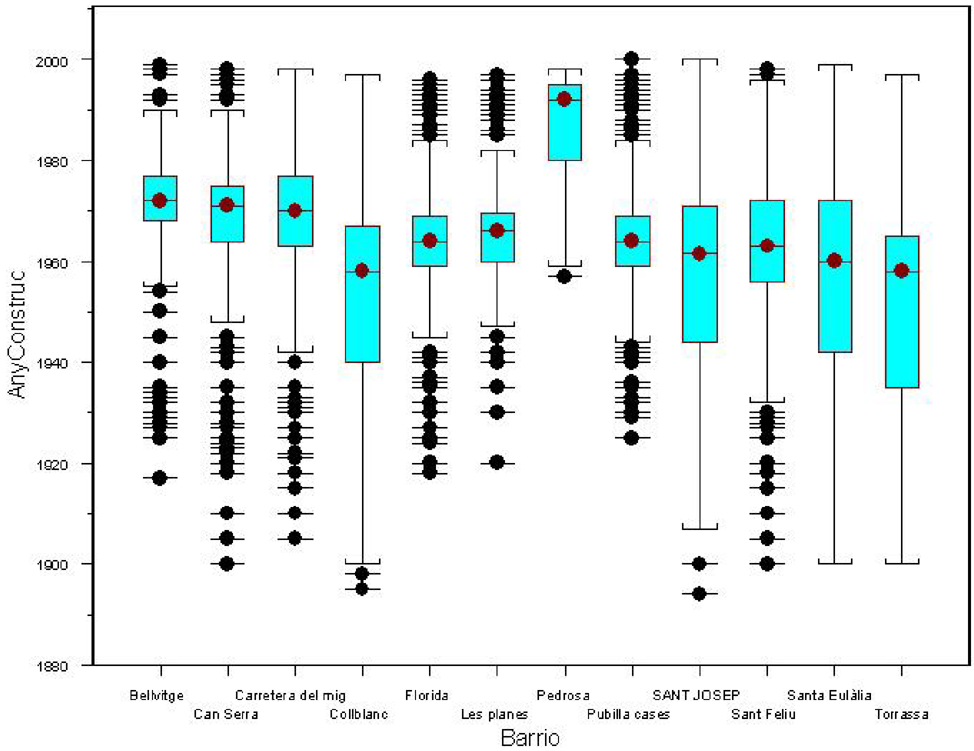


Figure 5.5 Boxplot by construction year without outliers for each neighbourhood of the city. Source: Gibert-Royano 2010

This new distribution by neighborhoods also shows sufficient homogeneity, as they all presented medians close to 1,965, highlighting the neighborhood Pedrosa with a lower median of 1.992 as the youngest neighborhood. Another situation is described in Collblanc, Santa Eulalia and Torrassa neighborhoods, whose medium is placed next to 1960, being the oldest and with a greater variability.

Finally, without considering outliers that represented a total of 109 facades of the total 10,150, 10,041 remain operational, which is considered a sufficiently representative sample to conduct the study.

As the results sorted by neighbourhoods do not differ excessively from the overall study of the sample, it has been decided not to study the durability by subsamples, because in doing so, the amount of the sample was weakening. That is why the results of the graphics that have been shown in this paper reflect the status of all facades that have entered the final study of the built park in the city of Hospitalet de Llobregat.

In earlier studies there have been permormed a migration of the information from the databases of the Laboratory of Building to the S-PLUS program. The result is shown in *Table*

5.5, made by Xavier Molons and Juan Pedro Liebana, where the new coding of all data found in the inspection records shown.

The new document, which follows similar organizational structures to field sheets, set out in each box a code for each estimator belonging to a specific structural element of the facade (rows), related to his injury, magnitude and severity (columns).

It is from this point that these new codes are employed to perform the functions of durability that will be discussed in the following sections.

5.3 Analysis of the results from the univariate model application

The univariate analysis consists in establish the evolution of each lesion to a certain magnitude, for each of the constructive elements of the facade. That study is done separately for the injuries of low, medium and high severity, ie, given one element and injury with a determined magnitude, its durability is estimated considering as the event of interest (or failure) the existence of an injury on a particular severity.

The data that is available is based on inspections in which each element belonging to the facade and, for each lesion with a certain magnitude, is established which is the potential hazard that represents to people.

In this case of univariate analysis, all elements of the same type are independent and are considered individuals who are at equal risk of injury.

As already mentioned in *section 4.5. Implementation of the methodology of analysis,* when an injury is manifested in an incipient manner with low gravity, with the passage of time this evolution is variable depending on the type of injury and the affected item and today, is unknown. Note that the elements that fail are those who during the inspection were quantified with an injury with severity 1, 2 and 3 and are considered left censored data because at the time of observation the injury already existed. Here are three severity levels that correspond to the classification defined in *Table 3.3* in Chapter III describes - *Design data collection*:

ESTIMADORES A EJECUTAR EN EL ANÁLISIS POR GRAVEDAD → Data frame: user.data

ESTIMADORES A EJECUTAR EN EL ANÁLISIS POR MAGNITUD → Matriz: matrix.max.mag

				LESIONES																								LESIONES							
Nº	ELEMENTOS CONSTRUCTIVOS	ACRÓNIMOS	MAT.	ROTURA (R)			FISURA (F)			DEGRADACIÓN MATERIAL (DM)			DEFORMACIÓN (D)			HUMEDAD (H)			OXIDACIÓN (O)			BUFADO (B)			DESCONCHADO (DC)			R	F	DM	D	H	O	B	DC
		MAGNITUD		P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G								
	CARACTERÍSTICAS DE FACHADA																																		
	CUERPO																																		
1	CF - Cuerpo / Paramentos 1	CF-C/P1	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	1	2	3	4	5	6	7	8
2	CF - Cuerpo / Paramentos 2	CF-C/P2	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	9	10	11	12	13	14	15	16
	HUECOS																																		
3	CF - Huecos / Dinteles 1	CF-BU/LL1	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	17	18	19	20	21	22	23	24
4	CF - Huecos / Jambas 1	CF-BU/BR1	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	25	26	27	28	29	30	31	32
5	CF - Huecos / Dinteles 2	CF-BU/LL2	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	33	34	35	36	37	38	39	40
6	CF - Huecos / Jambas 2	CF-BU/BR2	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	41	42	43	44	45	46	47	48
7	CF - Huecos / Antepechos	CF-BU/AM	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	49	50	51	52	53	54	55	56
	REVESTIMIENTOS DISCONTINUOS																																		
8	CF - Revestimientos / Aplacado 1	CF-RD/A1	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	57	58	59	60	61	62	63	64
9	CF - Revestimientos / Aplacado 2	CF-RD/A2	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	65	66	67	68	69	70	71	72
	REVESTIMIENTOS CONTINUOS																																		
10	CF - Revestimientos / Revoco	CF-RC/AR	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	73	74	75	76	77	78	79	80
11	CF - Revestimientos / Estucado	CF-RC/ET	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	81	82	83	84	85	86	87	88
12	CF - Revestimientos / Esgrafiado	CF-RC/EG	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	89	90	91	92	93	94	95	96
13	CF - Revestimientos / Pintado	CF-RC/PI	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	97	98	99	100	101	102	103	104
	BARANDILLA DE CUBIERTA																																		
14	CF - Barandilla de cubierta / Paramentos 1	CF-BC/P1	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	105	106	107	108	109	110	111	112
15	CF - Barandilla de cubierta / Paramentos 2	CF-BC/P2	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	113	114	115	116	117	118	119	120
16	CF - Barandilla de cubierta / Aplacado	CF-BC/A	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	121	122	123	124	125	126	127	128
17	CF - Barandilla de cubierta / Revoco	CF-BC/AR	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	129	130	131	132	133	134	135	136
18	CF - Barandilla de cubierta / Balaustradas	CF-BC/B	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	137	138	139	140	141	142	143	144
19	CF - Barandilla de cubierta / Remate	CF-BC/R	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	145	146	147	148	149	150	151	152
	CUERPOS SALIENTES																																		
	BARANDILLAS																																		
20	CS - Barandillas / Paramentos 1	CS-B/P1	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	153	154	155	156	157	158	159	160
21	CS - Barandillas / Paramentos 2	CS-B/P2	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	161	162	163	164	165	166	167	168
22	CS - Barandillas / Aplacado	CS-B/A	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	169	170	171	172	173	174	175	176
23	CS - Barandillas / Revoco	CS-B/AR	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	177	178	179	180	181	182	183	184
24	CS - Barandillas / Balaustradas	CS-B/B	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	185	186	187	188	189	190	191	192
25	CS - Barandillas / Remate	CS-B/R	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	193	194	195	196	197	198	199	200
	BALCONES																																		
26	CS - Balcones / Losas 1	CS-BL/LL1	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	201	202	203	204	205	206	207	208
27	CS - Balcones / Losas 2	CS-BL/LL2	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	209	210	211	212	213	214	215	216
28	CS - Balcones / Cantos	CS-BL/C	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	217	218	219	220	221	222	223	224
29	CS - Balcones / Bajobalcón	CS-BL/SB	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	225	226	227	228	229	230	231	232
	TRIBUNAS																																		
30	CS - Tribunas / Paramentos 1	CS-TR/P1	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	233	234	235	236	237	238	239	240
31	CS - Tribunas / Paramentos 2	CS-TR/P2	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	241	242	243	244	245	246	247	248
32	CS - Tribunas / Aplacado	CS-TR/A	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	249	250	251	252	253	254	255	256
33	CS - Tribunas / Revoco	CS-TR/AR	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	257	258	259	260	261	262	263	264
34	CS - Tribunas / Estucado	CS-TR/ET	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	265	266	267	268	269	270	271	272
35	CS - Tribunas / Esgrafiado	CS-TR/EG	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	273	274	275	276	277	278	279	280
36	CS - Tribunas / Pintado	CS-TR/PI	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	281	282	283	284	285	286	287	288
37	CS - Tribunas / Dinteles	CS-TR/LL	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	289	290	291	292	293	294	295	296
38	CS - Tribunas / Jambas	CS-TR/BR	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	297	298	299	300	301	302	303	304
39	CS - Tribunas / Bajotribuna	CS-TR/ST	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	305	306	307	308	309	310	311	312
	OTROS ELEMENTOS																																		
40	CS - Otros elementos / Zócalo	CS-AE/S	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	313	314	315	316	317	318	319	320
41	CS - Otros elementos / Ménsulas	CS-AE/MS	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	321	322	323	324	325	326	327	328
42	CS - Otros elementos / Impostas	CS-AE/I	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	329	330	331	332	333	334	335	336
43	CS - Otros elementos / Cornisas	CS-AE/CR	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	337	338	339	340	341	342	343	344
44	CS - Otros elementos / Aleros	CS-AE/RF	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	345	346	347	348	349	350	351	352
45	CS - Otros elementos / Pescantes	CS-AE/PS	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	353	354	355	356	357	358	359	360
46	CS - Otros elementos / Molduras	CS-AE/MT	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	361	362	363	364	365	366	367	368
47	CS - Otros elementos / Otros 1	CS-AE/AL1	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	369	370	371	372	373	374	375	376
48	CS - Otros elementos / Otros 2	CS-AE/AL2	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	377	378	379	380	381	382	383	384

Table 5.4: Distribution of the estimators for the execution of the durability and hazard functions. Source: Gibert-Royano 2010

- Severity Level 1: estimation where it is considered that the event of interest (or failure) is the presence of a lesion in low severity. These individuals in the future may suffer an injury of medium or high severity.
- Severity Level 2: estimation where it is considered that the event of interest (or failure) is the presence of a lesion in medium severity. These individuals have in the past suffered an injury of severity 1 and in the future may suffer high injury severity.
- Severity Level 3: estimation where it is considered that the event of interest (or failure) is the presence of a lesion in high gravity. These individuals in the past have experienced a severity 1 and 2 injury.

Once the analysis is performed by severity it has been carried out a second analysis focused on the development of the existence of each of the injuries with a certain magnitude for each of the constructive elements of the facades. The durability is estimated considering as failure the existence of injury in punctual, local and general magnitude, regardless of the severity or risk to people.

As discussed above, injuries at its birth or first manifestation are punctual, then evolve over the time and increase in magnitude, becoming local and, finally, become general. So, the magnitude analysis is performed in three levels:

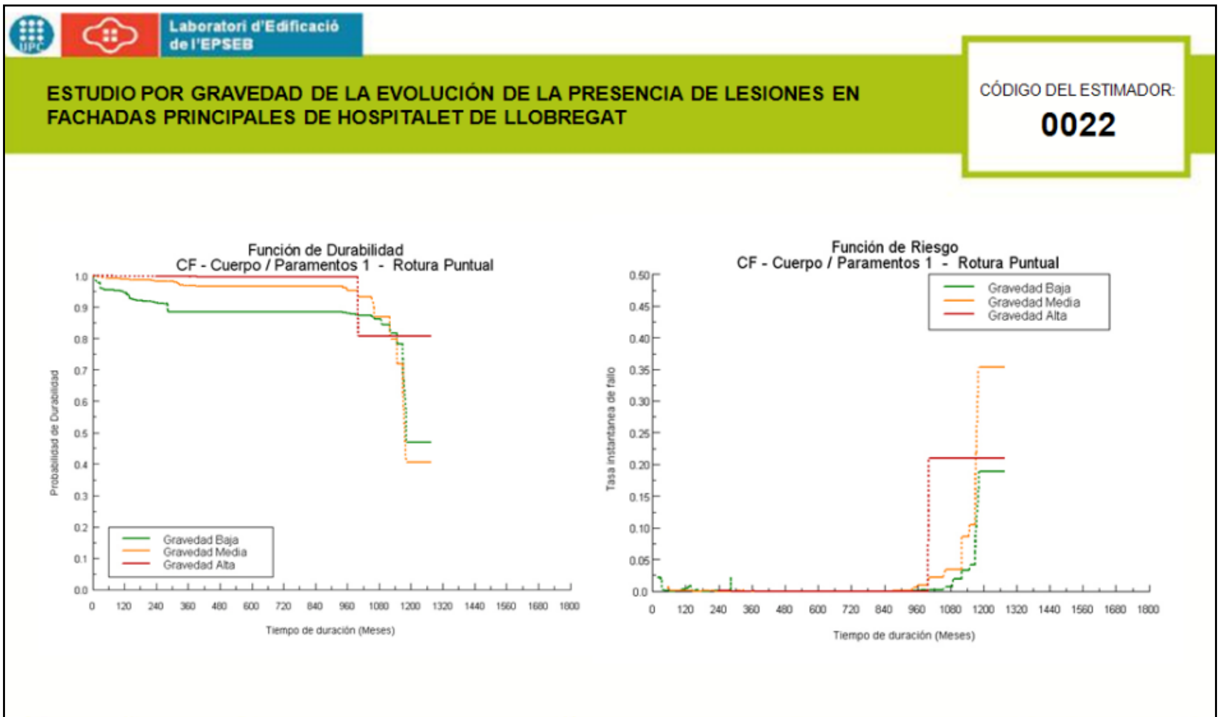
- Punctual magnitude: estimation where it is considered that the event of interest (or failure) affects, at most, 25% of the observed surface of the construction element.
- Local magnitude: estimation where it is considered that the event of interest (or failure) affects between 25 and 50% of the surface of the construction element observed.
- General magnitude: estimation where it is considered that the event of interest (or failure) affects more than 50% of the surface of the observed construction element.

In order to relate the different elements with their injuries, and to thus assign a certain level of severity and magnitude to each of them, the field sheet discussed in *section 3.3 Methodology of data collection*, belonging to *Chapter 3 design of data collection* was constructed.

To perform the analysis of durability and risk according to the severity and magnitude of the injuries, a series of functions whose purpose ranges from data collection of Turnbull estimator to the final realization of the graphics functions and durability hazard have been designed. Once executed the programming functions, the results are displayed on the tab that is presented in Figure 5.8 that provides graphical and numerical analysis information. The sheet of evolution of injuries, seeks to summarize and present in an easy and understandable way, the data that characterize each of the estimations All these sheets, along with associated graphics and tables, are available on the final project "*Cataloging and analysis durability and risk of injuries facades of Hospitalet de Llobregat, 2006," Nuria Barriuso Sprangers and Miquel Estupiña Gaudioso.*

The tables compare the tabs allow to compare each other the results obtained when the estimation is done on each item and injury for each magnitude considered (in the case of analysis of magnitude), and compare the results obtained by perform the estimation of each element and injury for each level of severity.

In order to help in the understanding of the data, the sheets are structured into three distinct zones: an upper zone in which the header is positioned to identify the type of study to be performed and the code estimator analyzed, an area formed by the central charts where estimates for the durability and hazard analysis are shown, and at the bottom in the summary table that associates the numeric data that is collected.



NUM. A RIESGO	% DE CENSURADOS		ESTIMACIÓN % LESIONES						TIEMPO EN AÑOS HASTA UN % ACUMULADO DE LESIONES				%ACUMULADO DE LESIONES EN UN TIEMPO EN AÑOS				UMBRAL DE RIESGO	AÑOS CORTE CON UMBRAL	
			INICIAL			FINAL													
	IZQ	DCHA	AÑOS	%	RIESGO	AÑOS	%	RIESGO	10%	25%	50%	75%	10	25	50	100		t1	t2
10414	10.9	89.1	1.4	2.2	0.023	106.1	53.1	0.189	23.5	97.4	98.6	--	5.3	11.4	11.6	53.1	0.01	2.7	90.6
10414	2.8	97.2	4.6	0.8	0.008	106.1	59.5	0.354	88.4	95.7	98.1	--	1.0	1.7	3.2	59.5	0.01	83.3	83.3
10414	0.3	99.7	19.7	0.1	0.001	106.1	19.3	0.210	83.3	--	--	--	0.1	0.2	0.3	19.3	0.01	83.3	83.3

Figure 5.6: Sheet of evlutionof the injuries dependig of its severity (estimator 0022) Source: Gibert-Royano 2010

The charts show the levels of magnitude or severity, depending on the case analyzed with three different colors. For this project, the green line corresponds to an injury with punctual magnitude or low severity, the orange line corresponds to a lesion with local magnitude or medium severity, and the red line corresponds to a lesion with a general magnitude or high severity, although not necessarily for all the elements studied it has been able to estimate the three magnitudes or severities.

As mentioned in Chapter *IV - Proposed reliability analysis techniques in the building*, the graphics are formed by solid and dashed lines that set the time intervals estimated. These ranges have as their lower limit an observation censored by the left and as the upper limit the right censored observation (previous to the next left censored). To make possible for the Turnbull estimator estimate the durability in two time intervals, we must have at least two left censored observations in the dataset. The number of falls or durability variations is greater when higher the number of failures or left censored times in a row. The last durability estimated range has as upper limit the last right censored time. Figure 5.9 describes the concepts explained through the analysis of a real graph.

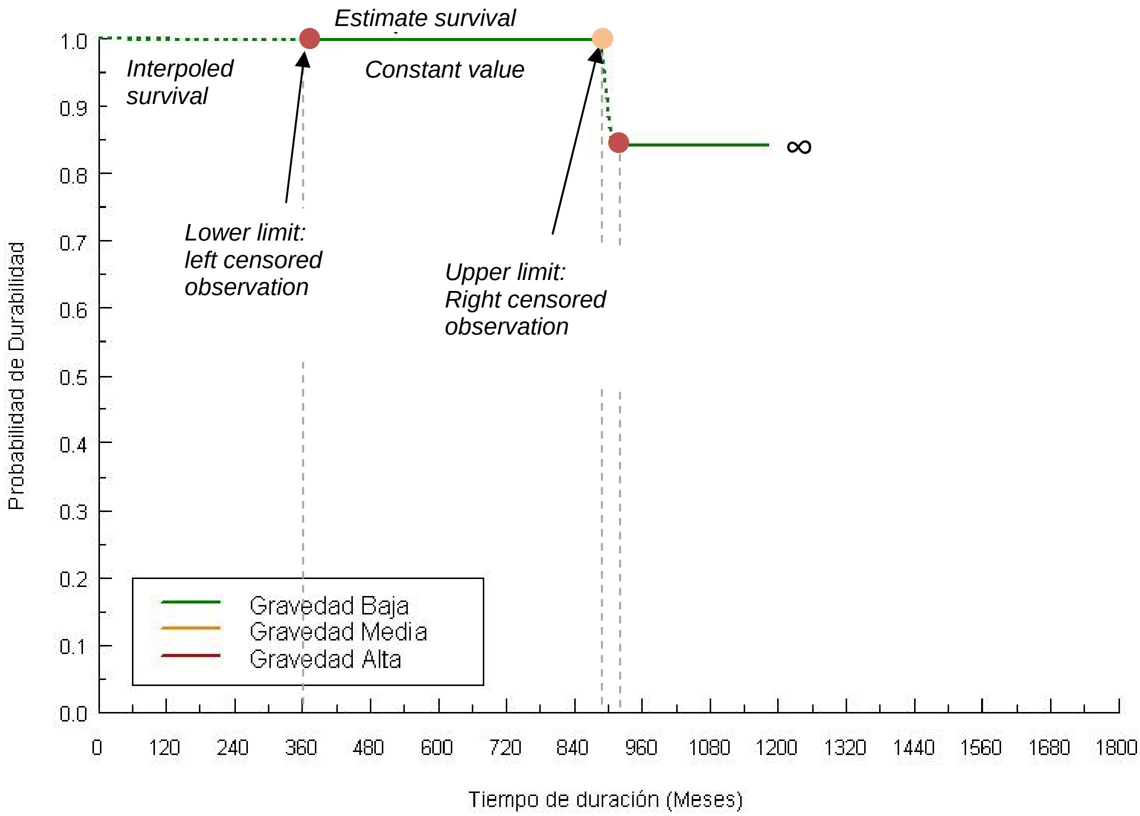


Figure 5.7: Durability function analysis. Source: Gibert-Royano 2010

In the lower part of the tab is found the Table 5.6 which is composed by an equal header for all cases, and three lower rows which show the three levels of magnitude or severity identified with the same color as shown in the graphs.

This table holds for each type of analysis some data that summarizes and express the evolution of failures and that have been obtained as a vector for each estimation.

NUM. A RIESGO	% DE CENSURADOS		ESTIMACIÓN % LESIONES						TIEMPO EN AÑOS HASTA UN % ACUMULADO DE LESIONES				%ACUMULADO DE LESIONES EN UN TIEMPO EN AÑOS				UMBRAL DE RIESGO	AÑOS CORTE CON UMBRAL	
			INICIAL			FINAL													
	IZQ	DCHA	AÑOS	%	RIESGO	AÑOS	%	RIESGO	10%	25%	50%	75%	10	25	50	100		t1	t2
10414	10.9	89.1	1.4	2.2	0.023	106.1	53.1	0.189	23.5	97.4	98.6	--	5.3	11.4	11.6	53.1	0.01	2.7	90.6
10414	2.8	97.2	4.6	0.8	0.008	106.1	59.5	0.354	88.4	95.7	98.1	--	1.0	1.7	3.2	59.5	0.01	83.3	83.3
10414	0.3	99.7	19.7	0.1	0.001	106.1	19.3	0.210	83.3	--	--	--	0.1	0.2	0.3	19.3	0.01	83.3	83.3

Table 5.5: Data summary placed in the lower part of the sheet. Source: Gibert-Royano 2010

The first number shown is the number of individuals who may suffer injury, that will not be the 10,041 facades that form the sample, but those that possess one or more times the item that is being studied and that therefore are susceptible of suffering the injury. Therefore, this value matches the severity analysis because the individuals at risk, ie, the facades that have the analyzed construction element, are the same. This is an important fact because the larger the number of individuals at risk, the more accurate the estimation will be. However, if it has an extremely low number it must be noticed that this may involve inferences. Similarly you can rely on an estimate calculated from a large number of elements at risk, it has to pay special attention to the interpretation of the estimates that have been obtained from a small number of elements at risk.

Then, in the second column, are following the values with the percentage of individuals censored by left and right with, related to the items that are at risk. These data are essential because they indicate, at the time of the inspection, how many failures had already occurred.

If the first estimation indicates a very high percentage of errors, and is established within a short period, indicates that the lesion occurs, in many cases, in a short time since the building construction. The last estimated value indicates that has been produced the highest failure rate and the moment when it occurs. From this value, it is not possible to perform estimation with the available data. The time of the final estimation corresponds to the right edge of last estimated range. If the estimated value of injuries equals 100%, the durability will be zero. This causes the right edge of last interval is extended to infinity, being considered as the time of the final estimation the left edge of this interval. In these cases, the value is accompanied by an "*" indicating that still pending for failure elements that have been censored on the right.

In the fourth number of Table 5.6 is placed the time in years until a cumulative injury percentage. These values provide an idea of how injuries over time for a given element are distributed, and provide values that compare these distributions between different building elements, injuries and magnitudes. It have been established four significant observation values, in relation to time which has to occur for the item studied, 10%, 25%, 50% or 75% of the observed injury. Between the failure estimation intervals there are periods in which there has not been possible to calculate the estimation. In these cases, is considered that the distribution in these periods is continuously and gradually, so that from the possible forms that may occur the drop of the durability (or the higher failures), it is considered a uniform continuous drop, being the interpolated value that also corresponds to the graph.

The following number is the accumulated percentage of injuries in a time in years. These data give an idea of the evolution of injuries over the time for a given item, and from these, some values that help to observe the injuries that occur faster than others are obtained.

The risk threshold located in the penultimate column is a set value as a basis to decide, by comparison with it, if the calculated effective risk is affordable or acceptable. This threshold is represented by a value from which the graph of hazard function takes a constant value over a period of time, and has been fixed at 0.01 from the analysis of the behavior of all the estimations obtained.

Finally, the years that cross the risk threshold in points t_1 and t_2 are displayed. Usually the graphics resulting from the hazard function $h(t)$ have the form of bathtub curve (concept as explained in section *4.3 Fundamentals*). In the early years the three magnitudes have a decreasing risk until the moment near to t_1 (first point of crossing with the rate of threshold), from which they take a low and almost constant value, to grow and reach again high risk values around t_2 (second cross point with the rate of threshold).

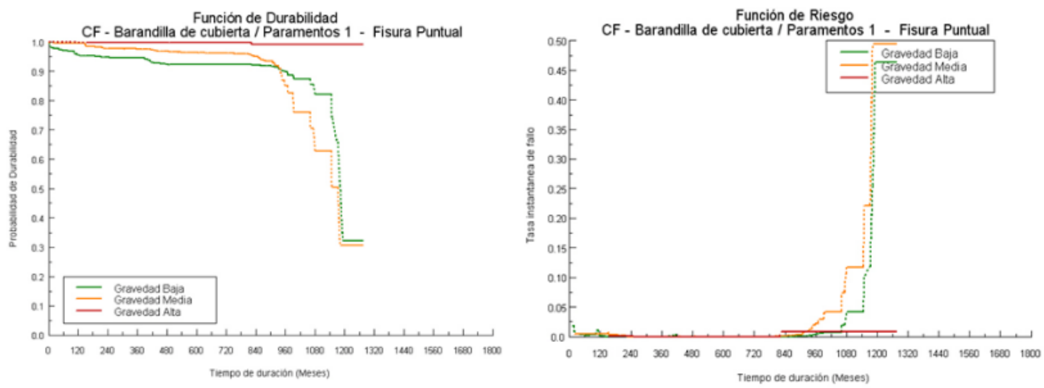
For ease the understanding of all the concepts explained in this section, a detailed interpretation of the results from one of the estimators from the catalog *"Punctual Crack – CF Roof railing / Walls 1"* example is presented. The estimator has assigned the code **0350** for the analysis of the severity (see *Figure 5.10*), and the code **0106** for the analysis of magnitude (see *Figure 5.11*).

With the data available it have been able to estimate the three levels of severity (low, medium and high) and magnitude (punctual, local and general).

Laboratori d'Edificació de l'EPSEB

ESTUDIO POR GRAVEDAD DE LA EVOLUCIÓN DE LA PRESENCIA DE LESIONES EN FACHADAS PRINCIPALES DE HOSPITALET DE LLOBREGAT

CÓDIGO DEL ESTIMADOR:
0350



NUM. A RIESGO	% DE CENSURADOS		ESTIMACIÓN % LESIONES						TIEMPO EN AÑOS HASTA UN % ACUMULADO DE LESIONES				%ACUMULADO DE LESIONES EN UN TIEMPO EN AÑOS				UMBRAL DE RIESGO	AÑOS CORTE CON UMBRAL	
			INICIAL			FINAL													
	IZQ	DCHA	AÑOS	%	RIESGO	AÑOS	%	RIESGO	10%	25%	50%	75%	10	25	50	100		t1	t2
8709	6.5	93.5	0.8	1.8	0.019	106.1	67.9	0.463	79.7	95.7	98.6	--	4.4	5.3	7.8	67.9	0.01	1.6	88.4
8709	3.0	97.0	1.7	0.4	0.004	106.1	69.3	0.495	78.4	88.4	97.8	--	0.4	2.3	3.6	69.3	0.01	77.7	77.7
8709	0.1	99.9	12.8	0.1	0.001	106.1	0.9	0.008	--	--	--	--	0.1	0.1	0.1	0.9	0.01	--	--

Figure 5.8: Sheet of injuries depending on its severity evolution (estimator 0350). Source: Gibert-Royano 2010

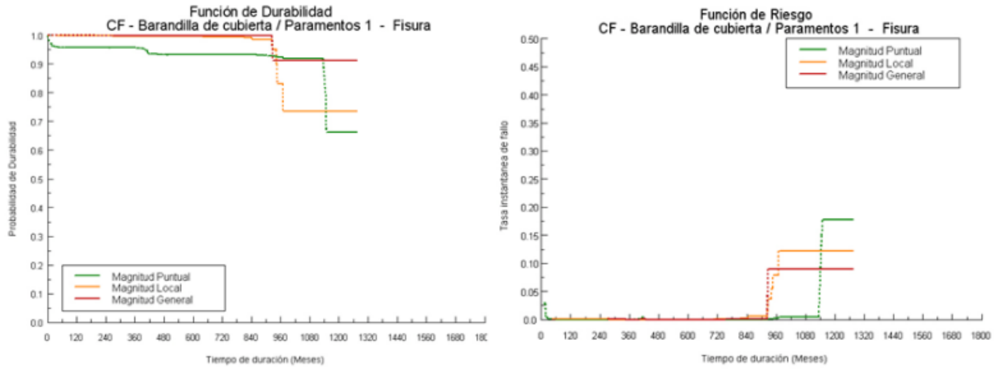
The sheet of injuries evolution corresponding to Figure 5.10 shows that the percentage of left-censored data differs for the three levels. To the low severity it is corresponded a 6.5%, while the medium severity a 3.0% and the 0.1% for the high severity. In the same sheet is found that the individuals at risk are 8,709, ie there are 8,709 facades with plastered coating of the 10,041 total constituting the sample of l'Hospitalet de Llobregat. According to the state of preservation found in the inspection of 8,709 facades,, there is 6.5%, which is equivalent to 567 facades, in low severity; 3.0%, equivalent to 262 facades, in medium severity; and 0.1%, corresponding to 88 facades, for the high severity.

From the analysis of the three lines representing the three estimated severities, the similarity between progression of low and medium severities is extracted. Shown how, with the passage of time, are estimated the lowest durabilities. Note the scarce presence of injuries with a high severity, which even prevents the estimation of the first decile; similarly, the estimating only of 0.9% of these injuries after 100 years.

Laboratori d'Edificació de l'EPSEB

ESTUDIO POR MAGNITUD DE LA EVOLUCIÓN DE LA PRESENCIA DE LESIONES EN FACHADAS PRINCIPALES DE HOSPITALET DE LLOBREGAT

CÓDIGO DEL ESTIMADOR: **0106**



NUM. A RIESGO	% DE CENSURADOS		ESTIMACIÓN % LESIONES						TIEMPO EN AÑOS HASTA UN % ACUMULADO DE LESIONES				%ACUMULADO DE LESIONES EN UN TIEMPO EN AÑOS				UMBRAL DE RIESGO	AÑOS CORTE CON UMBRAL	
			INICIAL			FINAL													
	IZQ	DCHA	AÑOS	%	RIESGO	AÑOS	%	RIESGO	10%	25%	50%	75%	10	25	50	100		t1	t2
8709	5.6	94.4	0.8	2.8	0.029	106.1	33.7	0.178	94.7	95.6	--	--	4.3	4.3	6.8	33.7	0.01	1.5	94.6
8709	0.4	99.6	3.5	0.1	0.001	106.1	26.5	0.122	78.6	80.9	--	--	0.1	0.3	0.5	26.5	0.01	77.1	77.1
8709	0.1	99.9	22.3	0.1	0.001	106.1	8.8	0.090	--	--	--	--	0.0	0.1	0.2	8.8	0.01	77.1	77.1

Figure 5.9 Sheet of evolution of the injuries depending on their magnitude (estimator 0106). Source: Gibert-Royano 2010

The graph of the hazard function significantly presents the theoretical "bathtub curve" previously discussed. The risk of suffering the injury in one of the three severities is similar in all sections, although it is more common to suffer a low severity injury at the beginning of the life of the building and, instead, at the end of the analysis indicates that it is more likely to suffer it in medium severity.

From the summary table located on the sheet of the severity analysis (*see Figure 5.10*), the following results are extracted:

- The third column of the table shows the estimation of the injuries depending on the observed moment, initial or final estimate. The first estimation appears at 0.8 years for a low severity injury, with 1.7 years for a medium, and 12.8 for high severity.
- For low severity there have been 1.8% of cracks in the elements at risk. For the medium severity this value is considerably lower, 0.4%, and the for the high severity, is much lower, only 0.1%. This indicates that in the early years of life many the cracks

are frequent, manifesting in the graph of the function of durability, in this case, in the initial part of the curves.

- By analyzing the risk function is observed than in the respective first estimate the probability that have the railings of deck to suffer cracks in low severity, knowing that at that moment have not failed yet, it is 0.019, a higher value than the rate of failure of 0.004 and 0.001 that present in medium and high severity, respectively.
- The final estimation corresponds to the right edge of the last interval and is produced for the three severities at 106.1 years; therefore, it has been able to describe a period of approximately 105 years of life for the deck railings. At that time, there would be a 67.9% of injuries in low severity, in medium severity would be on average 69.3% and for the high severity, would represent 0.90%. Another interpretation that can be done of this final estimation is that at 106.1 years, the failure rate that have deck railings to suffer cracks in low severity has increased to a failure rate of 0.463, and in medium severity to 0.495. In contrast, the failure rate of suffering in the high gravity has increased from a failure rate of 0.001, in the first estimation, to a rate of 0.008 in the latter.
- In the fourth number of the table it is studied the time in years until a determinate number of injuries, and it is detected that to reach the 10% of individuals with low severity cracks it should spend 79.7 years, to reach the failure of the 25% of the individuals we have to spend 95.7 years and, instead, the cracks will affect the 50% of the facades in 98.6 years.
- The study of intermediate estimations can also be performed to a time in years, as is shown in the following term. At 10 years it is observed that there has been 4.4% of fissures with low severity, having to spend about 15 years for 5.3% of injuries to occur. From this moment and for 50 years, the increase of injuries is minimal until at 100 years when the 67.9% of the facades have failed. In contrast for a local magnitude, at 10 years 0.4% of cracks, having to spend 25 years to affect the 2.3%, and another 25 years to again return to affect twice as many facades. From that moment is when the largest increase of failure occurs, affecting 69.3% of the facades when it reaches 100 years. Finally, at 10 years it occurs 0.1% of cracks with high severity and, from that moment, practically this figure does not increase and to affect the 0.90% of individuals will have to wait 90 more years.
- A Finally, a decreasing initial risk for the three severities is observed, up to a moment near to t_1 in which the risk for low severity is 1.6 years, for the medium severity is 77.7 years, and in the high severity events there are no risk thresholds for a threshold set

at a failure rate of 0.01, from which the three severities are kept low and constant. The second point of intersection with the threshold t_2 appears at the 88.4 years for the low severity and 77.7 years for the medium severity manifested with an increased risk in the graph.

In order to know globally the state of the facades of l'Hospitalet de Llobregat, and based on the sheets of the different estimators for analysis of magnitude and severity, were generated the tables that allow us to study in detail the behavior of each one of the constructive elements of the facades and see which suffer a greater number of injuries. All these tables can be consulted in the degree thesis *"Cataloging and analysis durability and risk of injuries facades of l'Hospitalet de Llobregat, 2006,"* Nuria Barriuso Sprangers and Miquel Estupiña Gaudioso.

Thanks to the particular study of the various elements it has been possible to perform a global analysis to observe the behavior of the 8 injuries which has been chosen for this study in the whole facade, to detect the most common injuries, and to determine which are more popular in severity and magnitude.

In the *Figure 5.12* it is introduced a bar graph in which the percentage of injuries on different facades of the building elements are displayed, compared to the total of found lesions (47,302).

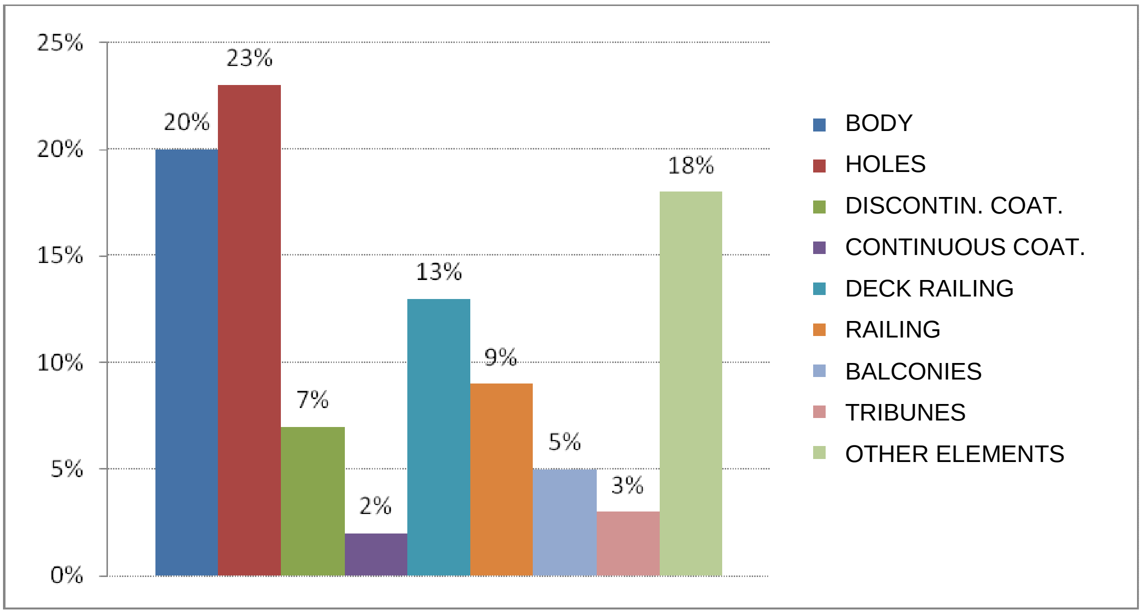


Figure 5.10: Percentage of injuries in the different constructive elements in the facades Source: Gibert-Royano 2010

The results show that the elements that suffer the most injuries are those located in the holes of the facades with 23%, followed by the body of the facade with 20%. The elements that have fewer injuries are the continuous coatings and the tribunes, with 2% and 3% respectively.

In *Figure 5.13* one can see the percentage of impact on the various injuries.

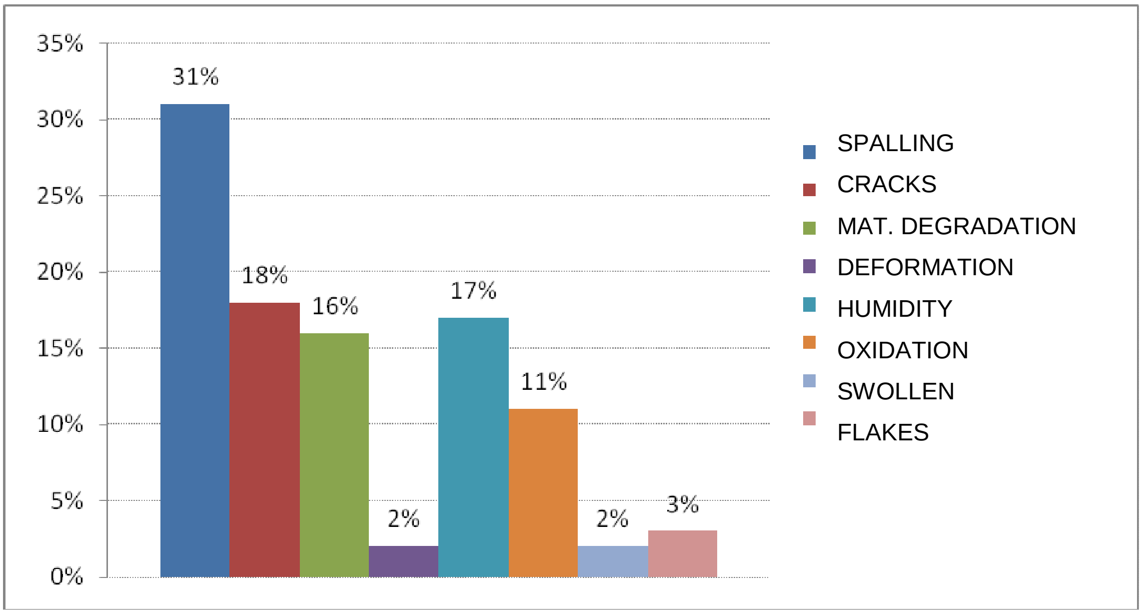


Figure 5.11: Percentage of affectation of the different injuries Source: Gibert-Royano 2010

In the results obtained, we must highlight the break as the most common injury with 31%, while the addition of deformation, swollen and flakes represents only 7% of the total.

Below the *Table 5.7* is introduced, in which is shown the percentage of susceptible constructive elements to present some kind of injury.

	INJURIES							
ELEMENTS AT RISK	R	F	DM	D	H	O	B	DC
BODY	29	26	16	1	15	4	2	1
HOLES	45	31	41	3	29	5	4	8
DISCONTINUOUS COAT	69	4	26	2	20	1	4	3
CONTINUOUS COAT	12	43	34	0	65	0	18	49
DECK RAILING	21	12	11	1	13	8	2	2
RAILING	20	6	5	0	7	37	1	1
BALCONIES	20	14	6	1	8	11	3	4
TRIBUNES	12	6	3	0	4	1	1	2
OTHER ELEMENTS	48	20	15	4	33	11	2	3

Table 5.6 Percentages of affected elements at risk. Adapted from: Gibert-Royano 2010

The data reveal that, of all continuous coatings analyzed, the 65% experience an injury with kind of humidity, whereas in the railings are detected a presence of oxidation in 37% of the cases. Also noteworthy is the high percentage of discontinuous coatings having breaks. In general, it can be said that, in greater or lesser degree, breakage lesions, fissures and material degradation, are present in virtually all elements of the facades. However, the deformation and swollen injuries provide less information. This fact should not be overlooked, since an adjustment about the kind of the injuries or a reduction of itself, may provide better end results.

Figure 5.14 stratifies the impact of different injuries for each of the constructive elements of the facades, so it is possible to determine the influence of each lesion on the total of found lesions in a given element.

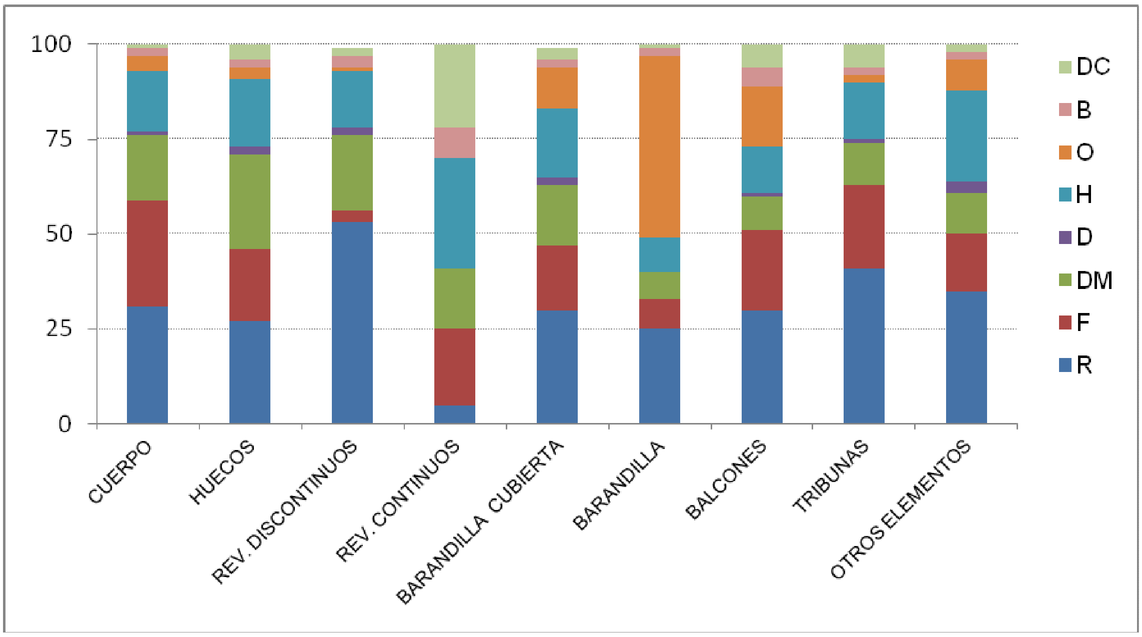


Figure 5.12: Accumulatives percentages of injuries in the different elements Source: Gibert-Royano 2010

The most relevant data are located on one side in discontinuous coatings, which have about 50% of their injuries focused on breaks and, secondly, on the railings, where we found the same percentage of lesions because of oxidations. From these results the following reflection arises: to increase the lifetime of the facades is necessary to pay special attention to the quality and type of materials and the implementation process as well as carry out a plan of timed maintenance. The high percentage of cracks in the tiling may be due to the poor quality of the material or incorrect execution method. In the case of oxidation on the railings, it is likely that has not been protected properly or has not been made sufficiently planned preventative maintenance.

To show an applicative of what could be the result of unifying the univariate charts of each studied element, depending on the severity and magnitude of the observed injuries, is shown the next contribution:

- The element under investigation will be the deck railing with plastered finishing (for this type of element it correspond 13 sheets in its univariate analysis).
- The study is focused on grouping the cumulative percentage of injury in time in years. According to the lower table on the sheets, these times are set to 10, 25, 50 and 100 years.

- The analysis of the presence of the observation in the element in based on the graph of durability, considering the time, the type and magnitude of the injury.

For this purpose all the values that are extracted from the sheets of the univariate analysis have been moved, and Table 5.8 is created, which relates the magnitude row (punctual, local or general) and the severity (low, medium or high). This is combined with the percentage of accumulation injury in periods of 10, 25, 50 and 100 years, while is shown the referred kind of injury in what the percentage represents over the total.

In the same Table 5.8 we can see that of the 8 studied lesions, some of them does not appear in the element, foreseeable situation because they are injures not possible to be observed by incompatibility between the type of injury and the type of material studied. This situation has wanted to emphasize, first because it shows a known fact, second because it validates, somehow, the data collection in the field and, finally, that has been a feature of all the work not to despise any value or information that could lead to some unexpected results.

Worth noting that in the row of material degradation at the time that inspection has been done, injuries were detected only in general magnitude. Therefore, in the boxes for local and punctual lesions the same underestimated values appear, so, at least this would be the observed value at the same moment for a local or punctual magnitude.

With all the information available it has been created the Figure 5.15. In it, a first row where the timing determined in years is shown, in the first and second column, the magnitude of injury and their type is established. In time slots it's shown the percentage represented by on the total of each of the injuries, and the significance of each of them, differentiated by colors.

In the graph it has been only represented the corresponding values to the average severities, because in the observations it have not been found high severities for this constructive element, and it has been chosen the first value that involves the intervention on the facades to represent a potential risk for people.

Another consideration has been to not place observations related to the 100 years given the size of the sample used, since the variability is so large that the estimation would be inaccurate.

In this case the sample is 149 facades which are which have the studied element. To remember that this sample represents the totality of individuals, therefore, based on the referenced data, could find out how many individuals would be affected by injury.

MAGNITUD	PUNTUAL												LOCAL												GENERAL											
% Acumulado de lesiones en un tiempo	10 AÑOS			25 AÑOS			50 AÑOS			100 AÑOS			10 AÑOS			25 AÑOS			50 AÑOS			100 AÑOS			10 AÑOS			25 AÑOS			50 AÑOS			100 AÑOS		
GRAVEDAD	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A
Rotura	0,8	0,5	0,0	1,9	1,4	0,0	3,3	2,7	0,0	0,0	0,0	0,0																								
Fisura	4,9	4,7	0,0	12,4	11,8	0,0	39,4	35,2	0,0	0,0	0,0	0,0	1,2	2,2	0,0	3,1	5,6	0,0	12,3	10,1	0,0	0,0	0,0	0,0	0,9	0,3	0,0	2,3	0,7	0,0	6,6	1,1	0,0	0,0	0,0	0,0
Degradación del material	12,1*	4,2*	0,0*	30,2*	10,5*	0,0*	85,8*	65,3*	0,0*	100,0*	100,0*	0,0*	12,1*	4,2*	0,0*	30,2*	10,5*	0,0*	85,8*	65,3*	0,0*	100,0*	100,0*	0,0*	12,1	4,2	0,0	30,2	10,5	0,0	85,8	65,3	0,0	100,0	100,0	0,0
Deformación																																				
Humedad	1,0	0,0	0,0	2,4	0,0	0,0	2,9	0,0	0,0	0,0	0,0	0,0	5,7	4,9	0,0	12,2	12,4	0,0	17,1	14,3	0,0	0,0	0,0	0,0	20,2	14,0	0,0	49,3	35,0	0,0	83,6	72,4	0,0	100,0	100,0	0,0
Oxidación																																				
Bufado	4,7	2,7	0,0	11,7	6,8	0,0	30,7	26,4	0,0	0,0	0,0	0,0	0,7	0,7	0,0	1,7	1,7	0,0	2,6	2,6	0,0	100,0	100,0	0,0	1,5	1,5	0,0	3,9	3,9	0,0	7,7	7,7	0,0	0,0	0,0	0,0
Desconchado	5,5	5,3	0,0	13,7	13,3	0,0	56,7	49,7	0,0	0,0	0,0	0,0	4,1	2,9	0,0	10,2	7,3	0,0	18,3	13,1	0,0	0,0	0,0	0,0	0,6	0,6	0,0	1,5	1,5	0,0	12,2	12,2	0,0	100,0	100,0	0,0

* Valor infraestimado

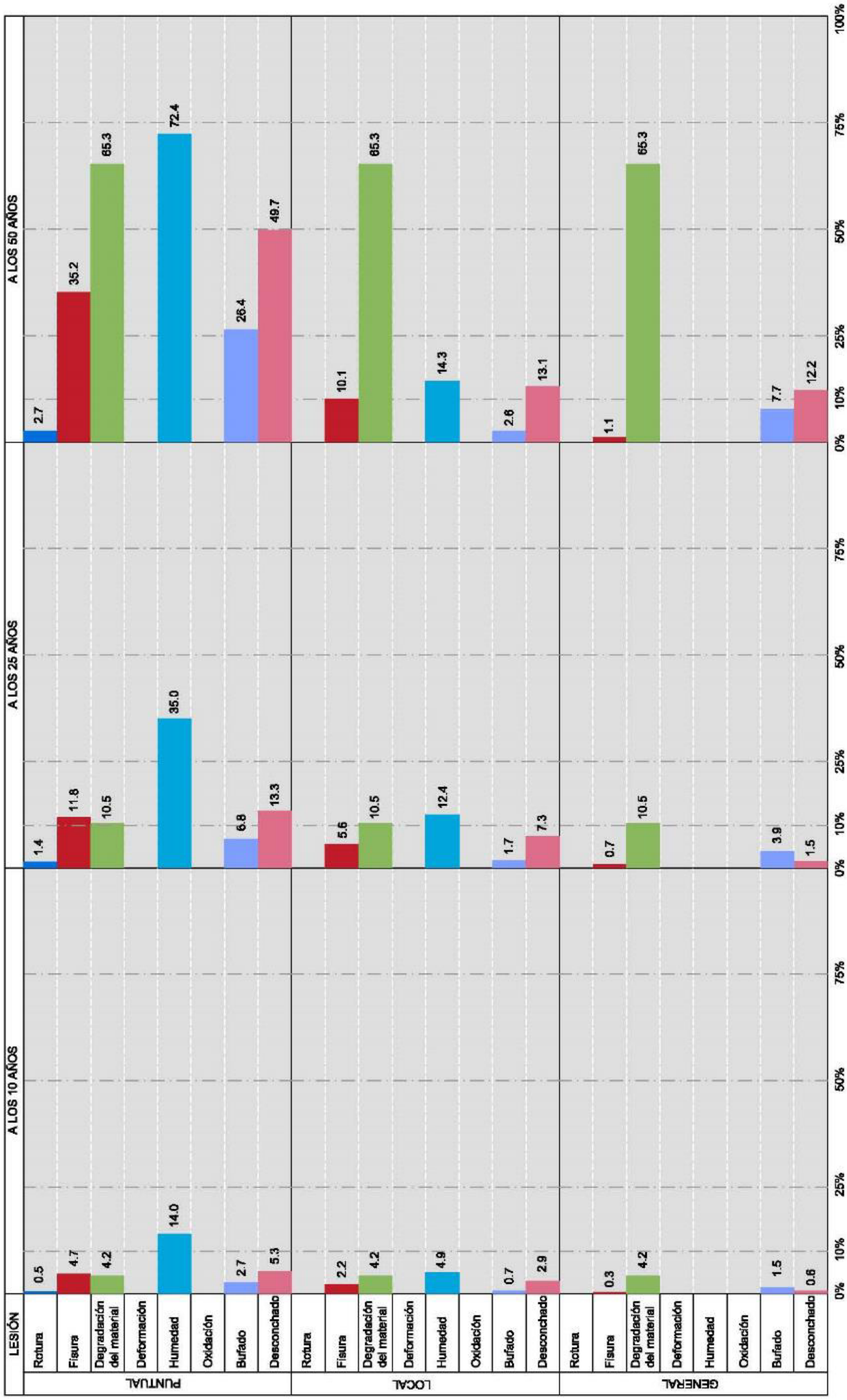


Figure 5.13: Percentages of injuries at a certain time. Source: Gibert-Royano 2010

If to introduce corrective actions we estimate that 10% involvement is the warning threshold, it would be thought that all those lesions that exceed this percentage would trigger the alarms to proceed to intervene the facades. In the studied case, to avoid the appearance of this percentage of injury in cracks, material degradation, flaking and moisture, should have been created corrective measures before the 25 year life of the building. If these measures are carried out appears another reality which is what stands out in the percentage jump between 25 and 50 years, a period in which this development is very significant in humidity, material degradation, chips and cracks as well in swollen and, although the latter are shown in a lesser extent.

The F*igure 5.15* not only determines the degree of involvement for each type of injury depending in time, but also constitutes a highly explanatory observation tool for decision-making, both technical and policy for intervention. Note that it is perfectly reflected from a certain age, the speed or rate of progression of lesions from the point of view of time and magnitude. This information seems of an extraordinarily remarkable interest because it can reveal information only intuited by the accumulation of professional experience.

5.4 Analysis of the results from the multivariate model application

In the study of durability and risk of the facades, different analyzes intended to estimate the behavior over time of the different construction elements are performed.

In *Section 5.4 Analysis of the results of applying the univariate model*, have been exposed the performed analysis to determine the different evolutions of injuries, according to the degree of hazard (severity analysis), and according to the area affected by injury (magnitude analysis). This section will proceed to the explanation of the analysis that characterize the durability taking into account other factors such as the coexistence of other injury or other structural element.

Once the primary and general analyzes are done, and to allow a more comprehensive study of the facades' data facades that are available, it is scheduled to perform these multivariate analyzes.

The appearance of a lesion can occur at different times depending on many factors that either promote his appearance, or delay it. So, the material from which an element is composed and its coexistence with another injured element or another injury, certainly can influence more or less to give a certain type of failure or injury in that same element. Multivariate analysis consists in finding those factors which may affect the durability of each element studied, by observing the behavior of the durability of an item when it involves a specific factor and when it does not, and estimating whether the difference between these curves durability is significant enough to say that this factor is influential.

Through this comparative analysis would be possible to answer questions such as:

- Can the elements have a different survival depending on the existence of another element?
- Can the injuries have a different evolution on an item if there are some other injuries?
- Can the elements have a lower survival depending on the material with which has been executed?

This answers can certainly be useful in making decisions regarding the maintenance of existing facades and design thereof.

As an example, below we present the methodology used in the case that would suppose to make a comparison of how evolve the several facades in which we find sumping injuries, on the basis of having or not materials deformations simultaneously.

For this analysis, the individuals at risk are the facades that also are at risk for each of the injuries considered, say A and B, in punctual, local or general magnitude. This risk facades set is subdivided into two groups according to suffer the injury B or not, and the goal is to examine the time until the lesion A in each group and comparing the resulting distributions. The difference between the distributions reports that times until the injury for the considered lesions are not independent.

To carry out this study, constructive assumptions for the statistical evaluation of the data are not imposed, but an exhaustive execution of the estimators is performed, so this way all the possible combinations of each estimator (element and injury) with other injuries are calculated. From the stored results, a particularized study graphics obtained, as shown in Figure 5.16, to investigate that what relationships may be explainable from the constructive point of view is performed.

In order to perform the multivariate analysis according to the coexistence of another and some other injuries as the magnitude thereof, a set of functions whose purpose goes from to obtain data from the Turnbull estimator, to the final performing and storing of the graphics depending on the durability.

To determine the existence or not of significant differences between the resulting non-parametric distributions, we used the proposed test by Gomez et al. (2004). The p-value, as illustrated in Figure 5.16, appears as a legend in the graph so that the user can obtain conclusions about whether or not significant differences exist between the two graphs from a certain confidence level. The significance level is obtained by subtracting to 1 the stablished confidence level. For example, if the user chooses to analyze charts with a confidence level of 0.999 (99.9%), as is the case of this project, it is considered that there are significant differences between the different curves if the p-value associated the graphic is less than 0.001 (1- 0999 = 0.001). In the field of statistics values most commonly used for the confidence level are 95%, 99% and 99.9%.

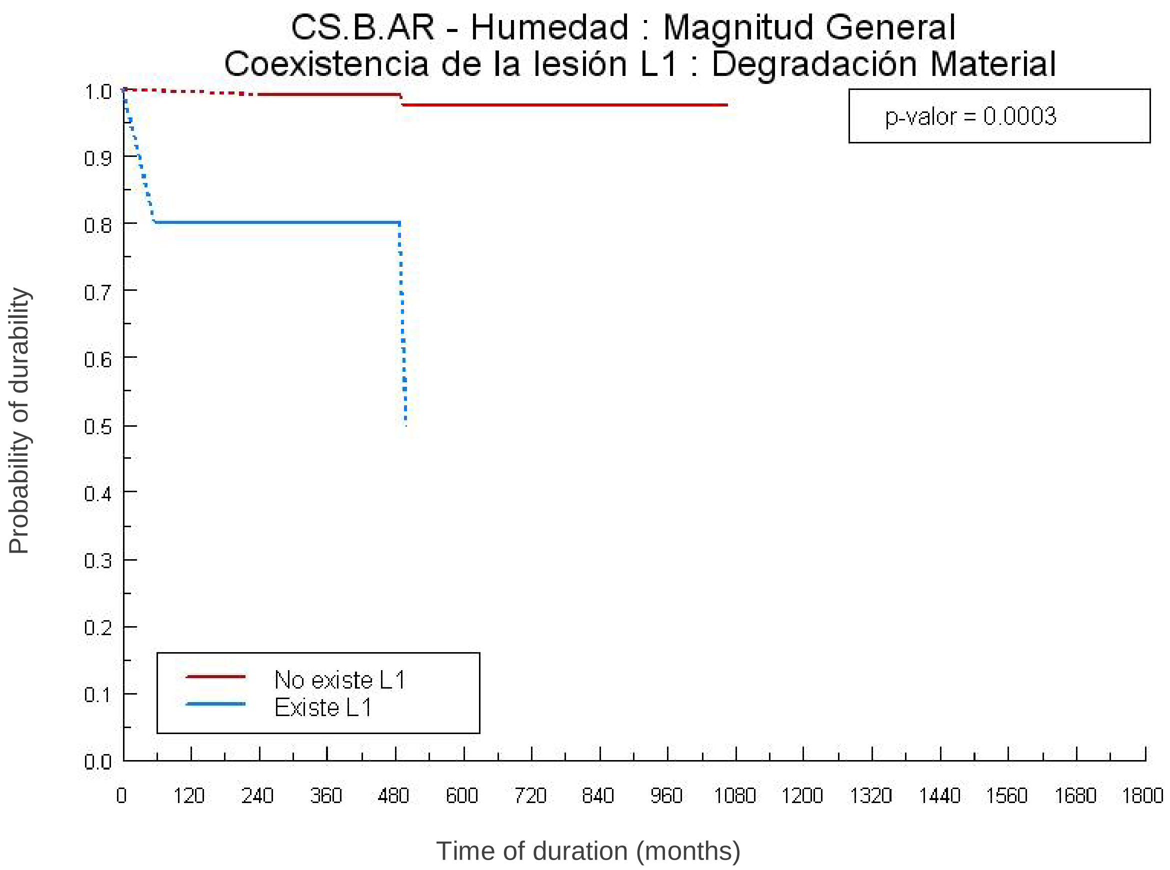


Figure 5.14: Chart of mutivariate analysis by injuries coexistance Source: Gibert-Royano 2010

Looking ahead to the interpretation of results, must be taken into account, together with the p-value obtained, sample circumstances that may affect the magnitude of this statistic as: a low number of individuals at risk, a big difference between individuals a coexistence risk of injury and to the absence of the same, a loss of a large number of individuals at the start of estimation, etc. In cases where the number of inspected facades is very high (greater number of individuals at risk), all these factors have less influence. It is not the same to have a sample of 350 facades inspected which have 80 individuals at risk and at the beginning 60 fail, that have a sample of 12,000 facades in which they are 3,000 individuals at risk and at the beginning where 60 also fail. In this second case, the remaining sample remains significant compared to the total and the large number of individuals at risk allows not to be displayed anomalous behaviors, since the behavior of most individuals masks the atypical behavior of a few of them, which does not occur in the first case, where any anomalous behavior of some individuals is not compensated by the standard behavior of other individuals.

6 MODEL APPLICATION IN OLSZTYN, POLAND

6.1 Introduction and historical background

Under the agreement collaboration between the Polytechnic University of Catalonia and the University of Warmia and Mazury, it has emerged the opportunity to apply the methodology explained above in the city of Olsztyn, Poland.

This implementation project will establish a starting point for creating a new database which takes as the sample the buildings of the mentioned locality, and allow to future research lines at UWM to draw conclusions about the status and characteristics of its urban park. In turn, this project also allows to extend the sample hitherto existing and resolve minor adjustments that must be made to apply the methodology in a totally different environment than the studied so far.Olsztyn is a city located at the northeast of the country, with an area of 88.43km^2, of which 20% is covered by forests and 8.75% by rivers or lakes; and a population according to 2010 data, of about 177,000 inhabitants. It is the capital, and most important town of the Warmian-Masurian Voivodeship, and is located at 213 km north direction of the country's capital, Warsaw.

The standardization of the methodology and its consolidation globally, is one of the main objectives of the project. The application outside the normal scope of the study will lead to a larger sample, and in turn, different building characteristics of the inspected buildings will lead us to propose different causal hypotheses.

Figure 6.1: Olsztyn localization. Source: Google

Due to logistical and temporal issues, being unable to inspect a larger number of facades, and continuing with the idea of globalization of the project, the goal of implementing the methodology in Olsztyn is no other than form a group of technicians in the standardized data acquisition procedure described above, than with a short time will be able to collect an amount of data significant enough to reach conclusions with statistical data base.

How to proceed with the methodology has been transferred to the teachers of the Faculty of Geodesy, at the University of Warmia and Mazury, that in turn will select a sample of students in advanced courses to perform in the future a data collection like the detailed in previous sections, and which has allowed us to accumulate the sample object of our study.

The idea with which we it works is that this methodology can be extended to many more centers, working as a satellite to the laboratory building where the process emerged, so, that once established the core (at the Laboratory Building the Polytechnic School building in

Barcelona, EPSEB) some othe knowledge ceters may join and provide data continuously to allow the sample grow to the greatest extent. In this way the homogenization of the sample, will allow to investigate many more aspects that the ones so far developed.

Worth noting that to achieve the objectives proposed the working methodology, as data is concerned, must be identically the same as used so far. The rigidity in the process of data collection is essential to avoid slippages in terms of qualification criteria for injuries that distort the total sample, incorporating to it invalid for our study elements that may be taken into account.

6.2 Urban characteristics and selection criteria of the sample

As discussed in the previous section the town of Olsztyn has an area of 88.43 km^2, with the difference that 20% of it is covered by forests, and 8.75% from lakes or rivers. This means that, along with the number of inhabitants (177,000 approx) the distribution of the urban fabric of the city is not compact, finding multiple cores of buildings in different areas of the city.

Figure 6.2. Olsztyn map. Source: Google Maps

Note that, for example Barcelona, with a population of 1,611,822 inhabitants, only has an area of 100.39 km2. So the ratio in Olsztyn which relates people with surface could be qualified as low. This density indicator gives us an idea of the little cluster of buildings, since the surface of unbuilt land is high. Here, by way of illustration of this idea, some other examples are shown.

City	***Population***	***Surface (km^2)***	***Ratio Hab/km^2***
Olsztyn	177.000	88,43	**2.001,58**
Warsaw	1.725.000	517,00	3.336,58
Barcelona	1.600.000	101,35	15.786,88
Paris	2.250.000	105,40	21.347,24
London	8.175.000	1.572,00	5.200,38

Table 6.1 Pobational data of some European cities. Source: Wikipedia

Similarly, the roads of the city do not create a compact mesh but are structured around large avenues that connect the different sub cores of the same urban area.

To all the factors discussed above we must add the traditional design of Polish residential buildings. Generally these buildings are tall blocks of flats, with a large number of residences in it, which are slightly separated from the street frontline with an urbanized and garden area around it.

Therefore, there are major differences in the characteristics of the constructive properties found in Olsztyn regarding on which the methodology has been applied so far.

Because of this, we must carefully choose the buildings on which we apply the methodology, requiring that they fulfill the prerequisites for being part of our sample.

The first basic premise that buildings objects of our study must comply is the alignment of its facade to the road. This is because otherwise, the durability of the elements that comprise may be altered (more longevity) as not being directly exposed to the effects of movement of persons and vehicles nearby, as are the other buildings inspected so far.

Another second feature, must be not having had its facade remodeled either partial or integral. Obviously this affects significantly the durability of the facade, thus distorting their actual age and the duration that can be estimated compared to others who have not undergone any action and already are included in the sample.

So we moved on to assess the suitability of the area Kortowo, which may be considered object of our study. Its proposal was due to the geographical proximity to the university buildings, and light logistics effords that would be needed to study the buildings found in it. However, the urban network we found it does not match the above requirements because of the large number of wooded areas, and because the buildings are isolated both among themselves and of the roads of the city.

Figura 6.3. Área de Kortowo. Source: Google Maps

Once having rejected for study the area in which it would have been more affordable to perform the study of its buildings, we moved on to choose an area that would meet the previously mentioned requirements, and was resembled completely the location and the construction characteristics to the buildings studied so far.

The chosen area corresponds to the area located in the northeast of the historical center of the city (*see Figure 6.4*) where the one of the city core is formed. This area contains many buildings that are perfectly suited to the basic requirements for be examined. The buildings we found are aligned to the vial, and grouped around it forming interiors gardens.

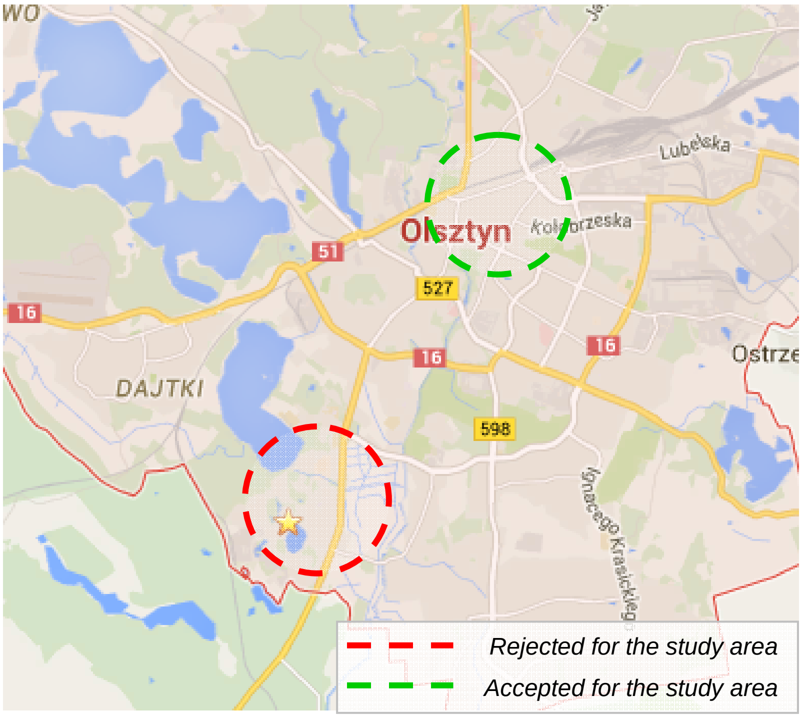


Figure 6.4: Considered areas for being studied.

The buildings we found are relatively low compared to the usual height of residential buildings in the city, facilitating visual inspection of the entire facade. Moreover, in the same phase of inspection, those subjects who present facades that have suffered interventions to alleviate its wear will be discarded, because they do not have the requirements detailed above.

Without discounting the latter cases, it is estimated that the potential size of this sample than will create the new object of study is approximately 350 facades, on which we will apply the methodology widely discussed.

6.3 Actions taken so far

In compliance of the established program for the methodology application, (detailed in the next section), and there have been permormed various tasks for implementing the method in Olsztyn.

Specifically, until the time of writing of this project has been carried out:

- *2nd week of October 2014:* First introduction of the working methodology to the project managers Dr. Anna Cellmer and Dr. Jacek Rapiński of the Faculty of Geodesy and Land Management UWM.

- *3rd week of October 2014:* Meeting with the different project coordinators for introduction of the methodology and detailed explanation of the sheets used in field inspections. Such unitholders are Dr. Anna Cellmer, Dr. Cezary Kowalczyk, Dr. Marta Gwiaździńska-Goraj and Dr. Sebastian Gwiaździńska.

- *4th week of October 2014:* Creation of groups of inspectors depending on the availability of students and project managers, and introduction of inspection schedule to perform.

- *1st week of November 2014:* Making in conjunction with the working group a preliminary inspection to visualize the procedure standardized for data collection and proper filling of the sheet field. This inspection was carried out in the area of Kortowo, and served as the basis for rejection of this area to be included in the study sample.

- *2nd week of November 2014:* Meeting to assess the adequacy of the study area of buildings proposed for the managers of the project. Acceptance of the proposed area and determination of dates for first inspections.

- *4th week of November 2014:* Fieldwork to perform the first inspections on the chosen area. Collection of the first data to add to the sample.

- *1st week of December 2014:* collection process control, and continuation of the fieldwork started earlier. Resolution of doubts emerged in the processing of previously collected data.

- *3rd week of January 2015:* pooling of data collected so far and establishing the methodology for building a database.

- *4th week of January 2015:* study of the inspected area (Reflected in Figure 6.7) and planning tasks that still remain to be done ahead of the coming weeks.

In this section is summarized the whole process of implementing the durability platform analysis in Olsztyn, which has in addition to the facts themselves, allowed assess new variables that were not envisaged a priori, and which directly affect the initial planning. A clear example is the academic calendar of the university, which determines the availability of students to form groups of inspection. Otherwise, yet even more crucial if anything, is the difficulty in performing technical inspections outdoors in winter time due to cold temperatures and adverse weather conditions that one finds.

Figure 6.5. Detail of the inspected area and buildings

6.4 Proposed timetable for full implementation of the methodology

In this section we will detail a proposal for the implementation of the several steps that we understand as essential for the proper and final implementation platform durability analysis in Olsztyn.

These processes are presented as a chronogram, and have been scheduled taking into account possible contingencies, establishing the time unit a half month, so that tasks can be performed flexibly in that time period.

The tasks we understand necessary, sorted chronologically are:

- Training: introduction to the potential candidates the methodology for data collecting. Explanation of the field sheet, performing initial inspections in group, in order to unify the criteria for evaluating injury and solving doubts that may affect the proper and reliable data collection.

- Data collecting: fieldwork itself. Inspections of the facades of the area that is assigned to each inspector and fill the field sheet depending on its condition.

- Data introduction: compilation of data collected and introducing them to the database through computer support.

- Data analysis: implementing the methodology explained above for statistical analysis of the data available in the database. Extraction of statistically relevant results.

- Dissemination of the results: publicize the work done and the results obtained at all levels: departmental, university, to the municipal entity, presentation in congresses and generate scientific papers for publication in specialized media.

In the timeline it can be seen how have been distributed the various tasks, and how are they overlapped in time. We understand that perform two tasks at once is essential in order to optimize resources

CALENDAR FOR METHODOLOGY'S IMPLEMENTATION

TASK	*Year*	2014						2015																							
	Month	OCT '14		NOV '14		DES '14		JAN '15		FEB '15		MAR '15		APR '15		MAY '15		JUN '15		JUL '15		AUG '15		SEP '15		OCT '15		NOV '15		DES '15	
	Half	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Training		X	X	X									X	X									X	X							
Data collecting					X	X			X	X				X	X	X	X	X						X	X	X	X	X			
Data introduction										X							X	X										X	X	X	
Data analysis											X								X											X	X
Dissemination										X	X							X	X										X	X	X

Table 6.2. Purposed calendar for methodology's implementation

CONCLUSIONS

7 CONCLUSIONS

7.1 Project's objectives

The main objective achieved with the implantation of the working platform in Olsztyn has been run the partnership between the Building Laboratory of the EPSEB and the faculty of Geodesy and Land Management of the UWM. This collaboration has provided the basis for the implementation of the methodology in Olsztyn, which we hope will motivate researchers to further develop the project and give a great result.

In turn, having transferred the knowledge on the methodology of those responsible at the University of Warmia and Mazoury in Olsztyn, will allow in the near future to be used as a teaching tool, forming students who will acquire both constructive and statistics knowledge that emerge from it. At the same time it will also mean to have set a new center of expansion since college teachers may spread to other professionals the knowledge and dealings of the durability analysis.

So the idea of the existence of a central laboratory Laboratory Building of the Polytechnic University of Catalonia in Barcelona and the co-existence of several laboratories worldwide, takes shape with this first step, by having been made on the faculty geodesy of the University of Warmia and Mazury the necessary actions so it become one of them.

Furthermore, the will of standardization of the procedure inevitably involves the validation of it in a different environment than the one performed so far, a fact that has been achieved. The implementation of all processes necessary for the application of the methodology has identified which tasks require special attention not to damage the reliability and validity of the results and the measures to be taken into account so that this does not happen.

Alongside these major objectives, derived secondary objectives of the application of the methodology have also been accomplished, such as identifying the singularities of the buildings in Olsztyn, the knowledge of which are the constructive characteristics more widespread in this region, adaptations had to be made to the initially planned phases due to factors such as the weather, etc ...

In summary, the continuation of work begun has managed to establish and demonstrate that the development and introduction of a system durability analysis on the behavior of the facades along the building's life, is able to emerge a knowledge, so far guessed, but never proved, on how and in what periods the failures occur, and what is its evolution over time.

7.2 Future proposals and lines of development

We hope that this work has aroused interest and motivation in people who have been in direct contact with the work carried out, and this is an encouragement to other technicians and scientists to continue investigating and testing new horizons, such as:

- The fulfillment and expanding the proposed schedule contained in section 6.4 to allow the project to continue developing and presenting new data.
- The extension of the methodology, both technical inspection as statistics, to other geographical areas which lend themselves to be studied, either in Olsztyn, or in other locations in Poland.
- Perform a detailed constructive study to understand the origin of injuries, their causes, and the evolution of these depending on the structural characteristics of the buildings.
- Create proposals for improvement in the construction process of buildings that can improve the durability of the previously observed elements.

Parallel to the implementation of the platform durability analysis, and together with Dr. Jacek Rapińsky, one of the teachers of the Faculty of geodesy of the UWM, is being developed a computer application that allows transferring the results obtained after applying all process described, to a viewing platform of Geographic Information Systems (GIS).

This tool will add to GIS software an application that will allows efficiently to execute survival analyzes within the same environment, and display the results on a map of the areas under study. Thus, when viewing the results, it is possible to surface new questions or conclusions to be drawn from our study.

The development of this tool has been possible thanks to an agreement between the two departments, and thanks to the invaluable collaboration of Jacek Rapiński and Michal Bednarczyk, who are supervising and executing its development

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8 BIBLIOGRAPHICAL REFERENCES

Books and papers:

Barriuso, N. y Estupiña, M. (2006), *Catalogación y análisis de la durabilidad y riesgo de las lesiones en fachadas de Hospitalet de Llobregat*. Degree final thesis EPSEB-UPC.

Buergel - Goodwin, E., Ferrara, C. and Bradley, P.E. (2005), Survival functions of buildings and building elements. *10th International Conference on Durability of Building Materials & Components*, Lion.

Flores, I. (2002), *Maintenance strategies: envelope of current buildings*. Master's thesis, Instituto Superior Técnico. Technical University of Lisbon, Lisbon.

Flourentzou, F., Brandt, E. and Wetzel, C. (2000), MEDIC – A method for predicting residual service life and refurbishment investment budgets, *Energy and Buildings*, 31, p. 167-170.

Gaspar, P. and De Brito, J. (2003), Service life prediction: identifying independent durability factors, in Proceedings of the RILEM/CIB/ISO. *2nd International Symposium, 'Integrated Life-time Engineering of Buildings and Civil Infrastructures'*, Kuopio, Finland, p. 319-324.

Gaspar, P. and De Brito, J. (2005a), Assessment of the overall degradation level of an element, based on field data. *10th International Conference on Durability of Building Materials & Components*, Lion.

Gaspar, P. and De Brito, J. (2008a), Quantifying environmental effects on cement-rendered facades: A comparison between different degradation indicators. *Building and Environment*, 43, p. 1818-1828.

Gibert, V. y Royano, V. (2010), *Determinación de estimadores de durabilidad adaptados a la edificación existente.* Master's final thesis EPSEB-UPC.

Gómez, G.; Calle, M. L.; Oller, R., (2004) Frequentist and Bayesian approaches for interval-censored data, *Statistical Papers,* 45, p. 157-161.

ISO 15686-1:2000, *Buildings and Constructed Assets* – Service Life Planning – Part 1: General Principles.

Jordana, F. i Gibert, V. (1999), *Pla pilot de l'estat de les façanes en edificis de l'Eixample*. ProEixample, Barcelona.

Kaplan, E. and Meier, P. (1958), Nonparametric estimation from incomplete observations. *Journal of the American Statistical Association*, 53, p. 457-481.

Liébana, J. P. y Molons, X. (2005), *Desarrollo de una plataforma de análisis de durabilidad de lesiones en fachada. Aplicaciones en Santiago y Valparaíso (Chile)*. Degree final thesis EPSEB-UPC.

Martín, S. (2004), *Análisis de "tiempo hasta la lesión" en fachada existente y su gravedad. Caracterización y predicción, en el caso de los patios interiores de l'Eixample de Barcelona.* Degree final thesis EPSEB-UPC.

Sarja, A. (2005), *Generic Description of Lifetime Engineering of Buildings and Civil Infrastructures. LIFETIME European Project*. Technical Research Centre of Finland VTT, Espoo, Finland.

Shoet, M. (1999), Deterioration patterns for maintenance management – A methodological approach. *8th International Conference on Durability of Building Materials & Components*, Vancouver, p. 1666-1678.

Shoet, I., Putterman, M. and Gilboa, E. (2002), Deterioration patterns of building cladding components for maintenance management. *Construction Management and Economics*, 20, p. 305-314.

Turnbull, B. (1976), The empirical distribution function with arbitrarily grouped, censured and truncated data. *Journal of the Royal Statistical Society,* Series B, 38, p. 290-295.

Web resources:

AENOR, [en línea]. Dirección URL: <http://www.aenor.es/>. [Consulta: 15 octubre 2009].

l’Hospitalet municipality, [on-line]. Dirección URL: <http://www.l-h.cat/>.

Wikipedia.com

Google resources